Figurative Thought and Language

6

How Metaphors Guide, Teach and Popularize Science

EDITED BY
Anke Beger
and Thomas H. Smith

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How Metaphors Guide, Teach and Popularize Science

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Volume 6

How Metaphors Guide, Teach and Popularize Science
Edited by Anke Beger and Thomas H. Smith

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Table of contents

CHAPTER 1
Introduction 1
Anke Beger and Thomas H. Smith

Part I. Metaphor in natural science and science education – an overview

CHAPTER 2
Social metaphors in cellular and molecular biology 41
Theodore L. Brown

CHAPTER 3
Coordinating metaphors in science, learning and instruction: The case of energy 73
Tamer G. Amin

Part II. Metaphor in science popularization – concepts of biology and biochemistry

CHAPTER 4
Metaphor and the popularization of contested technologies 113
Bettina Bock von Wülfingen

CHAPTER 5
To be or not to be: Reconsidering the metaphors of apoptosis in press popularisation articles 141
Julia T. Williams Camus

CHAPTER 6
Non-verbal and multimodal metaphors bring biology into the picture 175
José Manuel Ureña Gómez-Moreno

Part III. Metaphors in specific fields of social sciences and the humanities

CHAPTER 7
Three metaphors in social science: Use patterns and usefulness, separately and together **211**
Thomas H. Smith

CHAPTER 8
THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM: Following a metaphor's path from its birth to teaching philosophy decades later **263**
Anke Beger

Conclusion: When metaphors serve scientific ends **297**
Thomas H. Smith and Anke Beger

Index **319**

CHAPTER 1

Introduction

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In this introduction, we start by providing an overview of how metaphor makes science accessible (§ 1). The first part describes the intended readership of this book and introduces them to studies of metaphor in science. We then provide the theoretical foundation for the study of metaphor in science that all of the contributions in this volume are based on: Conceptual Metaphor Theory (§ 2). The third part (§ 3) introduces the three interrelated functions or levels of metaphor that are vital for making science accessible: language, thought, and communication. An overview of contributions to this volume concludes this chapter (§ 4).

1. How metaphor makes science accessible

The motivation for this edited volume on metaphor as a means to make science more accessible is a desire to discuss the essential functions of metaphor in conducting, teaching, and popularization of science. We want these fundamental functions to be concentrated within a single volume – a book that is itself accessible to scientists, science teachers, and science popularizers – and to lead to a better understanding of science, science pedagogy and, hopefully, better science.

1.1 Accessible to whom? Intended readership of this book

Whereas readers of texts written by scientists or popularizers of science are primarily interested in the scientific topic being elucidated, readers of this volume will attend not only to each scientific topic but also to how the metaphors work to explain them – to make the scientific topic accessible. This book is of interest to various groups of people who work in, study, or are interested in science and science education or popularization. However, we organize these groups into three categories according to common interests or roles within the fields of science and metaphor.

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The first category of intended readership includes scientists as well as science educators, popularizers or journalists, each operating within their own scientific, pedagogical and popularized discourse communities. While these professions, as well as their general audiences, differ in their detailed roles, they have in common that they communicate science to others. Whether their audience consists of colleagues, students, or the interested public, members of this category should find this book helpful in actually *enhancing* science accessibility. In correspondence with this shared interest, scientists as well as science educators, popularizers or journalists are collectively referred to here as *science communicators*.

The second category of readers are *metaphor scholars*. They are experts in metaphor rather than science, but study metaphor in a variety of discourses, possibly including science. For metaphor scholars, this volume is valuable because it provides them with insights of forms and functions of metaphor in yet another very important and broad discourse domain.

Finally, intended readers include those who read about science as specialists, students, or others interested in science and its explication. They share an interest in having science made more accessible for them. These groups of readers are referred to here as *audiences* or *audience members*.

1.2 An overview of the study of metaphor in science

The value of metaphor in science and science pedagogy was recognized as early as in Ortony's 1979 collection of chapters on metaphor and thought that featured an entire section of contributions on this topic. Since then metaphor research has developed considerably: negotiation of what constitutes a metaphor, improved methods, and wider fields of application. Despite these developments there have been few promising studies published or reported at recent conferences that, although beneficial to metaphor scholars, effectively addressed our other groups of intended readership.

Over the last 15–20 years, publications on metaphor in science and science popularization have been rather scattered, which makes it difficult to quickly establish an overview of the role of metaphor in science. Furthermore, it is often the case that only one of the three aspects of metaphor in science, that is, conduct of science, teaching of science, popularization of science, is addressed. Thus, prior publications often lack the synthesizing effect that is needed, as these three aspects of science are deeply intertwined. Most monographs and edited volumes focus on metaphor in science conduct, neglecting science pedagogy and popularization (e.g., Brown, 2003; Ervas, Gola & Rossi, 2017; Hallyn, 2000; Nerlich, Elliott

& Larson, 2009).[1] The few books that include science popularization or science pedagogy either do not take into account new methodological developments in metaphor analysis (e.g., Giles 2008) or are not exclusively devoted to science discourses, reporting on specialist discourse in general (e.g., Herrmann & Sardinha, 2015, which, interestingly, besides science and other technical subjects, includes metaphor in football radio commentary).

Considering the various studies in these works, some general conclusions can be drawn at this point.

- First, the degree of conscious or intentional use of metaphor can be seen to vary widely. Some scientists are meticulous in their use of analogical models, such as the nineteenth century physicist James Maxwell, who is said to have helped with visualization of lines of magnetic force by explicitly stating the analogy of fluids in motion (Miller, 2000, p. 149). Some science communicators focus intently on the rhetorical impact of metaphors; THE HEART IS A PUMP is widely employed to frame what the heart does hydraulically with blood pressured through pipes, emphasizing prominent features of the circulatory system without contradicting common knowledge of the heart as an exquisite and complex organ. Contrast this with how others, sadly, "are oblivious to the pervasive workings of conceptual metaphor in shaping our conceptual systems [...] constraining inferences in ordinary thinking, scientific research, and philosophical theorizing" (Johnson, 2007, p. 200). Among many possible examples is Darwin's use of EVOLUTIONARY CHANGE IS JOURNEY and GENETIC MODIFICATION IS CHANGE IN PHYSICAL SUBSTANCE, further represented in terms of family and a genealogical tree without any recognition that the Theory of Evolution recruited mappings from these conceptual metaphors (Drogosz, 2016).
- Second, metaphors are essential to scientists themselves and strongly influence science communication. Just to take one instance, scientists talk metaphorically of quantities or variables as points on a physical line, a line that is continuous and without gaps (Núñez, 2000). So entrenched is this example of metaphor that, without it, scientific measurements could hardly be communicated at all.
- Third, including the above and much else, there is a general interest in metaphor in science that continues unabated, particularly in the most recent works (e.g., Ervas, Gola & Rossi, 2017; Herrmann & Sardinha, 2015). However, as Cameron observes in the preface of Hermann and Sardinha's (2015) volume, it is vital to a deeper exploration of metaphor in scientific discourse to take

1. While the edited volume by Ervas, Gola, and Rossi (2017) does feature a section with articles on metaphor in education, the contributions are not necessarily concerned with the use of metaphors when teaching scientific content.

into account an important shift of metaphor studies, namely, to a more discourse-based point of departure (cf. Cameron, 2015, pp. xi–xii). In our view, more carefully documented analyses of metaphors as they are actually used in science texts, recordings, or videos is key in making science more accessible.

2. Theoretical foundations for the study of metaphor in science

Metaphor studies have shifted in several ways over the past decades, both in terms of theories about metaphor and the methodological approaches taken. These changes are important to understand for those concerned about metaphor in science. This overview is intended not only for metaphor scholars, but also for anyone hoping to gain greater access to science and to improve science presentation.

2.1 Main tenets of Conceptual Metaphor Theory

The focus here on Conceptual Metaphor Theory (CMT, Lakoff & Johnson, 1980) as a theoretical foundation for studying metaphor has two justifications: One, despite alternative theories of metaphor (for wide-ranging reviews see Gibbs, 2008, and Holyoak & Stamenković, 2018), our reading of the current literature puts CMT as still the leading paradigm for metaphor studies in Cognitive Linguistics and Applied Linguistics. The second reason is a reflection of the first and is that most chapters in this volume heavily draw on CMT as a theoretical basis. So we start this introductory chapter by reviewing the main assumptions underlying CMT (2.1.1), before we address critical aspects (2.1.2).

2.1.1 *Conceptual Metaphor Theory: Main tenets and assumptions*

In Conceptual Metaphor Theory, metaphor is primarily seen as a cognitive phenomenon, as a mapping between two conceptual domains (Lakoff & Johnson, 1980; Lakoff, 1993). The basic and most important function of metaphor is that it makes an abstract or less familiar domain (e.g., ELECTRICITY) accessible through a mapping from a concrete or more familiar domain (e.g., FLUID), whereby a mapping is considered a set of correspondences (e.g., 'the flowing of fluids' corresponds to 'electric current' and 'obstacles in the flow of water' correspond to 'electrical impedance'). Lakoff and Johnson (1980) argue that our ordinary thinking is largely structured by such metaphorical mappings. The notion of metaphor as a phenomenon of thought rather than merely a feature of language is quite powerful in that it presumes that we need metaphor to reason about all kinds of abstract concepts. Since science is predominantly concerned with examining abstract and/

or unfamiliar concepts, metaphor is, according to CMT, an indispensable tool in making science accessible.

While metaphor is seen as primarily a cognitive element, Lakoff and Johnson (1980, p. 7) argue that we can study metaphor in thought (conceptual metaphors) by examining language. According to CMT, we find patterns of metaphor in ordinary language that are systematic in that numerous metaphorical expressions come from one lexical field (e.g., "fluids") but are used to metaphorically talk about a different topic (e.g., "electricity"). This systematicity in metaphor use in everyday language is seen as a surface manifestation of conceptual mappings (Lakoff, 1993, p. 244).[2] Thus, within the CMT paradigm, linguists and other metaphor scholars have been analyzing metaphors in language to uncover conceptual structures for the past four decades.

Another aspect of CMT which is important for science and science communication is the notion of partial mappings. While a conceptual metaphor like ELECTRICITY IS A FLUID maps aspects from the source domain FLUID to the target domain ELECTRICITY to allow us to understand electricity in terms of fluids, the mapping between the two domains is only partial. That is, only certain aspects in fact correspond between fluids and electricity, and only those can be used to reason about electricity in terms of fluids. It is important for science communicators to be aware of the actual or useful correspondences as well as the limitations of the mapping to avoid risking that audience members make wrong inferences about the nature of the target domain (topic). If audience members transfer parts of the metaphor's source domain (e.g., FLUID) to its target domain (e.g., ELECTRICITY) that are *not* part of the useful mapping (e.g., fluid viscosity or thickness maps inaccurately to electrical impedance), they are likely to form a faulty concept of the topic at hand.

2.1.2 *Criticism of CMT and alternative approaches*

Although Lakoff and Johnson (1980) are chiefly interested in metaphor as a cognitive phenomenon, their early works do not include any support from psychological or psycholinguistic experiments to test their hypotheses about the cognitive structures or the psychological reality of metaphors. Instead, the reasoning of CMT is based solely on linguistic 'evidence'. While this disregard garnered criticism, it also stimulated numerous experimental studies that found psychological or psycholinguistic support for the existence of conceptual metaphors which (partially) structure our understanding (see, e.g., overview in Gibbs, 2011). However, the claim

2. Of course, the finding that metaphor is actually a pervasive feature of ordinary language is also one of the major achievements of Lakoff and Johnson's work. In this introduction, though, we restrict ourselves to the aspects most important for the articles in the present volume.

that our cognition is partially structured by underlying conceptual metaphors also raised the question of how far these mappings are activated in online (i.e., in-the-moment, spontaneous, unconscious, real time) processing of verbal metaphors. That is, do we indeed need to activate the underlying mapping of ELECTRICITY IS A FLUID, for instance, when we encounter the linguistic metaphor *flow* in a sentence like “Electricity can *flow* through a battery” in order to understand the sentence?

For the present volume on making science accessible via metaphor, this is important. Much research has been devoted to this question and up to now, no conclusive answer has resulted. A number of experimental studies have found that people do *not* usually process conventional metaphors in language by activating cross-domain comparisons (e.g., Bowdle & Gentner, 2005; Gentner & Bowdle, 2001; Glucksberg, Brown, & McGlone, 1993; Glucksberg & McGlone, 1999; McGlone, 1996). Instead, when encountering conventional metaphors in language, we seem to make use of different cognitive mechanisms. Competing approaches to metaphor such as Conceptual Blending Theory (e.g., Fauconnier & Turner, 2008), Relevance Theory (e.g., Sperber & Wilson, 2008) or Class-Inclusion Theory (e.g., Glucksberg, 2001, 2008; Glucksberg & McGlone, 1999) have therefore been put forward to provide alternative accounts for verbal metaphor processing.

However, since metaphor in science deals not only with conventional metaphors but also with novel ones, the most important model of metaphor processing for the present purposes is perhaps the “Career of Metaphor” model proposed by Gentner and her colleagues. Their “career” model of metaphor resulted from a series of experiments which investigated the processing of metaphors with different degrees of conventionality (cf. Bowdle & Gentner, 2005; Gentner & Bowdle, 2001; Gentner et al., 2001). Their findings are in line with both CMT, which suggests that metaphor is processed by cross-domain comparison, and Glucksberg’s Class-Inclusion Theory, which claims that metaphor is processed by categorization. That experiments support both CMT and the competing Class-Inclusion Theory may seem contradictory, but is resolved when considering the metaphors’ different degrees of conventionality. Apparently, we process metaphors with different cognitive mechanisms, depending on the metaphor’s degree of conventionality or novelty. Gentner and her colleagues maintain that *novel* metaphors are processed by cross-domain mappings (i.e., by comparison), the processing mechanism predicted by CMT (see Bowdle & Gentner, 2005). Once a metaphor becomes conventionalized, though, this changes. While early on during the process of conventionalization, a metaphor may still be processed by comparison (but can also be processed by categorization), the more conventional a metaphor becomes over time, the more likely it is to be processed by categorization. Finally, further on in a metaphor’s “career” of conventionalization, its literal meaning is no longer evoked during online processing, which makes cross-domain mappings impossible.

The criticism that CMT has faced with respect to the psychological reality of conceptual metaphors, as well as the ensuing experimental studies of metaphor processing, offer some conclusions for our present volume. First, CMT is a valuable approach to metaphor when we try to uncover people's general understanding of scientific concepts based on linguistic metaphors, as there is ample evidence that underlying conceptual metaphors partially structure our thought. Prevalent understandings of scientific concepts are in fact what most of the chapters of this book present in order to raise awareness of these patterns and to draw attention to problems of some popular conceptual metaphors in science and science communication. Second, CMT also seems to be able to account for our immediate understanding of scientific concepts when encountering metaphors in discourse events, particularly in cases where these metaphors are less conventionalized and/or reinforced when presented together through more than one sensory modality (e.g., visual and verbal). A number of chapters in this book deal with such presentations of metaphor in science and science communication.

Apart from criticism about the psychological reality of conceptual metaphors, though, CMT has also been criticized for its use of decontextualized examples, instances that especially illustrate the metaphor in question and often quite isolated from context. Anecdotes and natural language extracts were frequently cherry-picked or examples invented (causing difficulties as described by Deignan, 2012; Deignan, Littlemore & Semino, 2013, p. 7). Moreover, the focus on uncovering underlying conceptual structures by postulating them based on linguistic examples can be seen as a methodological deficit, compounded by assertions that Lakoff and Johnson's (1980) linguistic evidence had not been collected systematically and had in fact often been obtained by introspection (see, e.g., Jäkel, 2003, p. 134). This has led to a general neglect of a metaphor's linguistic form as well as its communication or discourse function (Caballero, 2003, p. 145) because it omits the ways that each such metaphor is found to be expressed in actual language.

These problems, particularly of earlier studies adopting the CMT framework, have led to the emergence of a growing body of research that, while still acknowledging most assumptions of CMT, focuses on the forms and functions of metaphors in particular discourse events (e.g., Beger, 2011, 2016, 2019; Beger & Jäkel, 2015; Deignan, Littlemore & Semino, 2013; Semino, 2008, 2011, 2016; Semino, Deignan & Littlemore, 2013; Semino, Demjen & Demmen, 2016). Systematically documenting the varieties of a metaphor's expression in real discourse goes beyond anecdotal evidence to provide an empirical basis from which to establish the generalizability of metaphor research. Communication or discourse functions of metaphor are particularly important when considering how the use of metaphors makes science more accessible and are therefore also addressed in our volume.

To summarize this overview of Conceptual Metaphor Theory, we can draw three conclusions. First, CMT is a viable approach to study metaphor in science, as it allows us to uncover metaphors that structure common beliefs about scientific concepts. Second, in science and science communication, certain groups of metaphors such as novel metaphors are likely to be processed by cross-domain comparison, thus potentially making audiences aware of the source domains at play. While linguistic realizations of metaphors were neglected in early accounts of CMT, more recent metaphor studies have adopted corpus analysis, discourse analysis and other methodologies that examine the forms of metaphor occurring in actual language. Third, CMT was originally not explicitly concerned with the functions of metaphor in discourse, but a growing body of research that is at least loosely tied to CMT demonstrates the value of examining what metaphors do in specific discourse events.

All three aspects of metaphor – its conceptual structure, linguistic realization, and communication or discourse function – are essential when examining how metaphor can make science more accessible. The next Section (3.) therefore provides theoretical accounts of these three interrelated functions or levels of metaphor.

3. Interrelated levels of metaphor in making science accessible: Linguistic, conceptual, and discourse functions

We shall now describe how the formulations and insights introduced by CMT have been elaborated and clarified over decades. As mentioned, three levels or functions of metaphor have emerged in the scholarly literature (see, e.g., Steen, 2008). These are usually identified as linguistic realization (the language function), conceptual structure (the function of conceptualization or thought), and metaphor in communication (the discourse function). These three functions are closely interrelated, but in the following sections, we will summarize the main theoretical aspects of each individually, as far as this is possible.

3.1 Metaphor in language – the language function

As already mentioned, although CMT theorists were largely concerned with metaphor in thought, direct study of the psychological reality of metaphor in cognition was rare. Instead, language examples were carefully examined to uncover linguistic realizations of metaphors. The distinctions that became bases for subsequent study, and which are particularly relevant for metaphor in science, are the conventionality or commonness of metaphors, versus their novelty. Of importance also are similes and analogies. Each of these are now discussed.

3.1.1 *Conventionality and novelty*

The most basic distinction among metaphors in language is that between *conventional* and *novel* metaphors. One of the major accomplishments of Lakoff and Johnson's seminal work *Metaphors We Live By* is in fact that they pointed out the wealth of conventional metaphors in ordinary English. Metaphors in everyday communication are so conventional, so frequently encountered, that we are usually not aware of their metaphoricity.

Novel metaphors, however, stand out due to the juxtaposition of words usually not associated with each other, attracting attention and stimulating unexpected comparisons. For example, "Jellyfish hold a key position at the phylogenetic base of the metazoan tree" may at first sound like a statement of an animal's particular physical location. But this novel sentence metaphorically depicts metazoa (multi-celled animals) as ranging from rudimentary to more complex, locating the jellyfish accordingly.

The degree of novelty of a metaphor is not fixed but changes over time. As mentioned above (2.1.2), Bowdle and Gentner's (2005) model of metaphor describes the development of a metaphor (its 'career') from novel to conventional to 'dead'. That is, when a metaphorical expression enters the language, it starts as a novel metaphor. Thus, novel metaphors are those that we usually recognize as a metaphor. If the community of speakers adopts the metaphor in question, uses it frequently, it will become conventional over time. Once a metaphor is conventionalized, we normally use it without paying attention to its metaphoricity. Moreover, a metaphor possibly conventionalizes to the degree that its literal sense has become inaccessible to the speakers, because the word is no longer used with its literal meaning, only with its metaphorical one (ibid).

This process of conventionalization can also be observed in science. Often, scientists coin a novel (set of) metaphor(s) when they are faced with a new discovery that needs to be described verbally. For instance, in the 1940s, when Erwin Schrödinger tried to hypothesize about the then still largely unknown processes of protein synthesis, he created the novel metaphor of the "chromosome code script", which developed into the "metaphor of the genetic code" (cf. Knudsen, 2003, p. 1251).

Knudsen (2005) gives the example of "genetic translation" where RNA serves as a template in synthesizing protein and thus the RNA "language" is "translated" into protein "language".[3] The novel conceptual metaphor here might be expressed as TRANSLATING GENES IS TRANSLATING LANGUAGE. This is conveniently expressed as a simile – translation from the RNA template to the protein is like

3. Lumen, Biology for Majors, Module 10, DNA transcription and translation. https://courses.lumenlearning.com/wmopen-biology1/chapter/translation/).

translation from one language into another – and this form may assist one's cognitive process (discussed more fully below) of looking for and finding the parallels between genetic translation and language translation, thus aligning source and target features. This metaphor, itself part of a root metaphor, "the genetic code," was so successful in generating lines of scientific inquiry that it spawned clusters of related metaphors now at the center of molecular biology (Knudsen, 2005).

But, per the "Career of Metaphor" hypothesis already discussed above, an innovative novel metaphor, once its terminology becomes familiar and its meaning categorized, the metaphor that was originally suggestive and open in its possible meanings is found to narrow or close, becoming less and less generative of new scientific ideas. Its terminology becomes more and more conventional, established, part of the scientific lexicon and settled in its descriptive role. It may even seem entirely literal, very much like a fact (no longer meriting scare quotes or italics). In the case of the genetic translation metaphor, after inspiring highly innovative research hypotheses and years appearing in scientific articles, later was found largely replaced by the biochemical details of scientific experimentation (Knudsen, 2005).

This would be a metaphor in the final stages of its "career" – a 'dead' metaphor. However, while scientific metaphors such as the 'genetic code' may become 'dead' (i.e., non-metaphorical) to scientists specializing in the field, conceptual structures persevere even when the early source domains are forgotten. So these same metaphors may yet be perceived as (strikingly) novel by people outside the scientific area (cf. Giles, 2008, p. 148).

This is a crucial aspect for science communicators. Expressions, including technical terms, which specialists may no longer regard as metaphorical, can be perceived as novel metaphors, and thus be processed by cross-domain comparison (see 2.1.2 above), by an audience new to the subject. Therefore, science communicators could unwittingly use established metaphors of the scientific field that may have unexpected impacts on their audience's understanding of the scientific concept in question. On the other hand, science communicators are often quite aware of the 'dead' metaphors in their field, which allows them to capitalize on their metaphoric and explanatory potential by using these metaphors in a purposeful or deliberate way to guide their audience's reasoning. For the 'genetic code' metaphor, for instance, Knudsen (2003, pp. 1254–1257) found that in popular science articles, science communicators often pointed out and explained the 'dead' metaphors for their non-specialist audience in order to use these metaphors for explanations of the genetic code.

To conclude this section, consider how the distinction between conventional and novel metaphors in language is important for making science accessible. In reading the chapters of this book one may note instances of novel metaphors that guide scientific conduct by providing inference structure that, in turn, stimulates hypothesis generation; not only is the scientist aided but also other audiences gain insight into the topic of study and how science is carried out. Even when these once-novel metaphors, retained and used over time among specialists, have become conventionalized within a particular scientific community and lose their metaphoricity, they contribute terminology to the field. We have seen how this may not be the end of their metaphorical usefulness to science. It has been shown that, writing for a non-specialist audience, science communicators facilitate understanding of scientific concepts by reviving the metaphoric meaning of conventionalized terms.

Apart from novel and conventional metaphors, we can also identify other forms of metaphor in scientific language: *similes* and *analogies*. Some readers may wonder why similes and analogies are regarded as metaphors and not as completely different tropes. The following sub-section will explain the degree to which similes and analogies are considered types of metaphor. Furthermore, their influence on science will be pointed out.

3.1.2 *Metaphor in a wider sense: Similes and analogies*

Metaphor, simile, and analogy are figures that differ in their linguistic form. Simile, for instance, typically appears in the form "A is *like* B", while a particle of comparison does usually not occur in the linguistic form of metaphor. There is ample evidence that metaphor and other tropes such as similes differ not only in the way they are processed (see, e.g., the overviews provided in Colston & Gibbs, 2017, pp. 462–463; Gibbs & Colston, 2012) but also in the way they are used in discourse. Thus, it is not surprising that metaphor, simile, and analogy are often considered to be distinct and that many scholars believe that similes and analogies are not simply types of metaphor. While we generally agree with these distinctions, we also concur with scholars (see, e.g., Ortony, 1993) who point out that metaphor, simile, and analogy bear important similarities based on which some researchers regard simile and analogy as special types of metaphors.

The important aspect shared by metaphor, simile, and analogy is the underlying cross-domain mapping, even if this mapping is not necessarily activated in the moment the figure is processed. Similes, with two distinct domains, most obviously involve a cross-domain mapping, since two unlike things are explicitly compared to one another in expressions or sentences such as "Science is like a glacier" (Steen, 2011a, p. 51). We are disposed to accept the argument that similes and metaphors belong to the same category of underlying cognitive processes, despite the fact that they differ in their linguistic realizations (explicit comparison in case of simile and implicit comparison in case of metaphor), online processing, and usage.

A similar argument can be made for any form of longer comparison that involves a cross-domain mapping, as is the case for numerous *analogies*. Analogies are also important for science, as we find many influential analogies in conducting and communicating science. For instance, the reader is probably familiar with the 'solar system' analogy for the description of atoms in chemistry or the 'factory' analogy to describe cells in biology.

Similes and analogies deserve special attention here – not only because they are an established linguistic tool in science, but also because they can impact one's reasoning just by virtue of their linguistic form. Such direct comparisons function similarly to novel metaphors (also cf. Steen, 2011b). The direct comparisons found in similes and analogies are likely to have a greater impact on the audience's understanding of a scientific concept than conventional metaphors because the latter no longer draw attention to a comparison with the source domain. The conceptualization of similes and analogies is discussed further in Section 3.2, below.

Metaphors in language can point to underlying conceptual metaphors that influence thought and generally structure reasoning and cognition. In the next section, a more detailed account of conceptual metaphors, that is, metaphor in thought, is given.

3.2 Metaphor in thought – the conceptual function

In examining the conceptual function, or metaphor in thought, one asks what a metaphor means and how it influences cognition or reasoning by offering a conceptual structure for understanding. Above (2.1.1), we mentioned that the conceptual function or level of metaphor has been the primary interest of the founders of CMT. The central tenet of metaphor in thought as depicted in CMT is a mapping from aspects of the more concrete or more familiar source domain to the more abstract, complex or unfamiliar target domain. Thus, in trying to understand a domain that is usually more abstract or unfamiliar to us, such as TIME or LOVE in everyday life, we make use of a domain that is better known, for instance MONEY or JOURNEY (cf. Lakoff & Johnson, 1980). What makes mapping from source to target domain possible is a set of correspondences between the two domains. The existence of a conceptual mapping between two domains is usually assumed if we find ample evidence in language, that is, if there are numerous metaphorical expressions which systematically reflect the given mapping. When such evidence exists, the metaphor would be referred to as a conceptual metaphor, customarily designated in print by small capitals (e.g. LIFE IS A JOURNEY).

Examining bodies of natural language for evidence of conceptual metaphors and their mappings is a painstaking process. As already mentioned above, the early researches in CMT relied on the reading of selected texts and subjectively identifying metaphors, then noting word use that implied what mappings are active. We already outlined criticisms of CMT, above, arising from this early methodology.

The metaphors found in this way may too often conform to the researchers' ideas and expectations. Inherent unreliability in such procedures inspired more rigorous identification methods to identify realizations of metaphor in language. The first widely recognized metaphor identification procedure, MIP, was published little more than a decade ago, by the Pragglejaz Group (2007). Soon after that, MIP was revised into MIPVU by Steen and his colleagues (Steen et al., 2010) who accommodated the procedure to less common but important types of metaphors, such as "direct metaphors" (that guide an audience explicitly to make a comparison between source and target domains, as occurs with similes). This trend takes into account genre and particular communicative aspects of metaphor in use (see Deignan, Littlemore & Semino, 2013; Semino, 2008).

Also, an array of corpus methodologies appeared that exploit computer software designed to produce concordances (e.g. Cameron & Low, 1999). Automated methods allowed metaphor researchers to comb large bodies of text for all manner of metaphors that might be found, accurately determine their frequencies, co-occurrences with other metaphors, and to see the natural variations in form. These methods helped to document occurrence of conceptual metaphors in various discourse types, quickly finding expressions in language which reflect a given metaphoric mapping. The availability of these more objective and rapid methods has clearly influenced the studies reported in this volume, elucidating a wider variety of metaphors, making clearer their degree of conventionality or novelty.

For metaphor in language, as discussed above (3.1.1), we differentiated between conventional and novel ones. The same basic distinction also holds for conceptual metaphors, but when metaphor researchers identify conceptual metaphors they declare their interest in how people cognitively process and make sense of the metaphor. A conventional conceptual metaphor source domain is one that is frequently shared in the particular language community and readily understood. This is because well-known elements of the source domain remain orderly and stable based on known semantic representations – "well-behaved mappings of words to meanings" (Veale, 2014, p. 53). For such conventional metaphors, mappings are automatic, rapid and largely unconscious, even though there is evidence that many complex embodied and conceptual processes are involved (Gibbs & Chen, 2018). Such well-behaved semantic representations have also been referred to as involving property-matching and analogy (mapping of structures in terms of relations) or category inclusion (target is member of a category of which the source is a prototype) (Gentner & Bowdle, 2006). When features of the source domain are frequently encountered, becoming familiar, even prototypical, these "coded meanings foremost in our mind" are said to be "salient" (Giora, 2008, p. 10) and easily accessed mentally, readily activated and mapped to the target domain.

Psycholinguistic studies attempt to understand the cognitive processes that enable metaphor conceptualization. While avoiding here the extensive theoretical debates about these conceptualization processes,[4] there is good evidence that certain metaphors are processed more easily than others, particularly direct, conventional metaphors that are apt, familiar and frequently used (Ashby et al., 2018 offer a review), and for individuals with stronger working memory and inhibitory control (Holyoak & Stamenković, 2018). They may be comprehended as well and as quickly as literal statements (Gibbs & Colston, 2012). But when metaphors are put in the surface form of simile (using "like" or "as"), an audience is linguistically cued to mentally compare the target domain to the source, potentially predisposing the mapping process. Metaphor, on the other hand, requires a cognitive search for previously formed correspondences (Gentner et al., 2001). Where psycholinguistic studies use eye-movements as indicators of cognitive processes, similes appear to work better than simple metaphors, yet much seems to depend on the details of the experimental tasks involved (Ashby et al., 2018).

The cognitive processing of both metaphors and similes have been described, starting with Aristotle, as analogical in nature – an ability to reason based on the relations between two different entities or domains (cf. Holyoak & Stamenković, 2018). Analogies have been said to organize information, make it more concrete, enable more efficient search and retrieval of source domain information from long-term memory, help visualize the source domain and perhaps assume the form of a logical argument (Shapiro, 1985). Although explication of an analogy may at first sound like a simile (e.g., a membrane is like a cookie), note is made of various similarities (a membrane has two layers of lipids [like Oreo cookie wafers]) and how these features relate to each other (layers are separated by a center [of white cream]).[5] As additional correspondences are given, the analogy goes beyond comparison based on similarity or resemblance of surface properties as occurs with similes, and promotes the deeper and more thorough mental process of mapping structural relations among source features (Kretz & Krawczyk, 2014, offer a review). This heightened attention to the source domain can put it at the forefront of the mind, make it more salient, easier to access and map to the target domain, as further discussed below regarding novel metaphors. Extended analogies are widely used in science to explain theories and instruct students, as the numerous examples in this book illustrate.

Because of their familiarity and physical realness, scientists may prefer conventional metaphors when they actually choose them consciously; early twentieth

4. Termed *Metaphor Wars* by Gibbs (2017), especially Chapters 4 and 5.

5. Example from http://www.metamia.com/analogize.php%3Fq%3Dq.

century physicists used metaphors that explained physics and became theory constitutive (Brown, 2003, p. 85; Gentner, 1982). But scientists so often do not choose them consciously (Knudsen, 2015; Smith, 2015). Because of their near-automatic use without awareness, science communicators can end up using metaphors that, while helpful in certain respects, are unintentionally confusing, even misleading. We see examples in the chapters of this book.

Novel metaphors, on the other hand, diverge from the conceptual norms and stereotypes that govern the meanings of conventional conceptual metaphors. They map source domain features that are not (yet) associated with the target, perhaps initially seeming 'unmappable'. Metaphor scholars have studied novel metaphors within artistic domains and poetry (such as Lakoff & Turner, 1989), but they also occur frequently in science, as chapters here illustrate. The meaning of novel metaphors depends on the process of somehow aligning source domain elements with target domain elements (Gentner et al., 2001) even though this may not happen easily. This alignment process is inferential and interpretive and occurs spontaneously in more of what has been called a "top-down" fashion (Giora, 2008, p. 144).

We will review how metaphor conceptualization and comprehension depends heavily on what kind of metaphor source domain is involved – those based broadly on bodily experience or what might be called social gestalt; also (and related) whether a source domain is concrete or relatively abstract. We will now describe in more detail two types of conceptual metaphors widely used to provide access to phenomena not directly perceivable and their relevance for making science accessible: *embodied metaphors* (3.2.1) and *socio-cultural metaphors* (3.2.2); this is followed by four attributes of conceptual metaphors that feature in chapters of this book and that will be of concern to the science communicator: source domain background knowledge (3.2.3), target domain background knowledge (3.2.4), how abstract a source domain might be (3.2.5), and combinations of metaphors (3.2.6).

3.2.1 *Embodied metaphors*

Research in this vein might be typified by focusing on some widely used and embodied source domain based on physical bodily experience; thus metaphor researchers term it 'embodied', such as journey (SCIENCE IS A JOURNEY: "biology progresses step-by-step") or movement (CHANGE IS MOVEMENT: "the theoretical viewpoint shifted"). Metaphor researchers then explore the various mappings of these rich source domains to reveal the conceptual structure that can be transferred to chosen target domains. We see, for example, that evolutionary biological processes are metaphorically conceived as a journey; when one maps features of a journey to biology, the evolution of a species can be characterized as following a path, encountering obstacles, pausing at intermediate points to re-orient and perhaps adjust its direction. A source domain such as JOURNEY is so common, one can easily find other target domains that it elucidates, such as LIVES, CAREERS, ECONOMIES; even DECORATING A CAKE can be conceptually structured with the same journey features.

In the course of early metaphor scholarship this focus on the conceptual structure of bodily movement showed that a relatively small number of metaphor source domains (such as the HUMAN BODY, HEALTH AND ILLNESS, ANIMALS, PLANTS, SUBSTANCES, OBJECTS, MOVEMENT, MACHINES, FORCE MECHANICS, CONSTRUCTIONS, CONTAINERS, GAMES AND SPORTS; cf. Kövecses, 2002; Liu, 2016) provide the form, logic, direction and constraints when thinking about a broad array of target domain activities, projects, theories, and understandings in science and everyday life. When combined, such metaphors complement each other or blend to shape understanding of highly complex topics (as discussed later).

When metaphor researchers have focused on the conceptual function of embodied metaphor, they have usually emphasized conventionality, unconscious use, concreteness, and complexity of source domains. Embodied source domains figure in research reported in this volume and their power in making science approachable is clearly shown.

3.2.2 *Socio-cultural metaphors*

Apart from conceptual metaphors whose source domains heavily draw on our physical experience of the world, we also find those that draw on a different class of experiences as human beings: our social or cultural experiences. These source domains exploit our knowledge of familiar habits of action such as established work and play activities, governing practices, crafts, or codified skills captured in writings, products, symbols, or other tangible, material objects (cf. Grassby, 2005). *Socio-cultural metaphors* may seem to be vague compared to *embodied metaphors*. However, they need not be vague if they are understood in terms of actual, concrete experience. Because socio-cultural metaphors are not so much experienced bodily, as culturally lived, they can depict interactions of separate entities at a higher macrocosmic level. Socio-cultural source domains can be complex gestalts that are culturally learned, characterized in terms of generic, structural dimensions as conventionally experienced (cf. Lakoff & Johnson, 1980, p. 202). The shared social experience of science communicators and their audiences enables them to form common gestalts or image schemas, becoming the basis for metaphoric source domains. Because gestalts arise naturally in social experience, they seem conceptually whole and coherent. For example, the experience of working with others in a group can provide an experiential basis for a conceptual metaphor source domain such as TEAMWORK that explains coordinated action among individuals and implies or predicts intention to achieve a goal.

Another example is geologic time (such as the age of the earth or when humans first appeared) that can be macroscopically viewed as the metaphor of a single calendar year; mapped accordingly, humans appeared during the afternoon of December 31st. The calendar year is understood primarily by daily living in a culture where experience yields a stable, conventional source domain for geologists and anthropologists to use in teaching students or the public about the place of humans in the vast expanse of geologic time. Other examples include the use of the domain of SECRET CODES or CIPHERS to describe and explain the process of protein synthesis, as mentioned above, or the use of religio-cultural expressions to characterize synthetic biology as "playing God" or "creating life" not only to inform the public about this new and noteworthy field but also to shift public perceptions (Braun et al., 2018).

We see in this volume several examples of how biological processes are metaphorically conceived as social phenomena, and mappings from a socio-cultural source domain are made to microscopic biological entities, giving them the executive capacities to make decisions, plan, gather resources, identify objectives, pause at intermediate points to re-orient. Just as cells combine to form differentiated organs with distinct functions at a macro level, socio-cultural source domains can be used to summarize and characterize these biological functions.

The demands of cognitive processing of metaphor, how it works for different types of metaphor and audiences with varying degrees of source domain familiarity, is a rich area of investigation. Evidence indicates that metaphoric language induces a cognitive, embodied simulation of what it would be like to experience the source domain, where the motor cortex appears to be recruited, displaying patterns of neural activation in parallel to that of language comprehension (Gibbs & Matlock, 2008). Still, such an embodied simulation would depend on one having had the relevant background, that is, the direct experience of the source domain (cf. Jamrozik et al., 2016).

3.2.3 *Source domain context or background knowledge*

Saliency will clearly depend on the context in which the metaphor is used and the degree to which context for the science communicator coincides with context for the audience. Understanding what a science communicator means depends heavily on context, including the circumstances in which the metaphor is used (cf. Carston, 2010).[6]

6. But note that "salient" or "coded meanings foremost in our mind" are challenged by Veale (2014) who asserts that established conceptual metaphor theories rely on these conventional conceptual mappings, not taking into account the empirical distributions and hierarchies of concepts of a particular language community.

Metaphors are introduced by science communicators in the first place to describe and explain scientific phenomena which are often complex and that cannot be perceived directly. How best can these metaphors enhance audiences' ability to think about and understand these phenomena? Often ignored is the rich context and much of the pragmatic knowledge that gives more abstract or less common metaphors their complex, inferential ideation (Holyoak & Stamenković, 2018). Giora (2008) has found that availability of meaningful source domain context (both local and global), coherence of this context, including when during metaphor processing this context can be accessed – are of key importance to assure efficient and full understanding; also important is contextual details of the situation in which the metaphor is applied (Carston, 2010; Oļehnoviča & Liepa, 2016). Case studies of metaphors in science, including some in this volume, illustrate the extent to which science communicators will go to provide adequate context for the metaphor source domain; the successes and failures are instructive.

3.2.4 *Target domain context or background knowledge*

It is not only the context of the source domain that is essential. Inadequate target domain background knowledge is also an issue. Occasionally scientific metaphors may be expressed with so little regard that the audience remains ignorant or confused about what target domain is being discussed, so a metaphor is less likely to help. This would occur if the education of the audience is far below the level assumed by the science communicator, or reference to the target domain is made using unfamiliar terms. Example: "A third-generation leptoquark might couple with a tau and a bottom quark" (Letzer, 2018, p. 1). This seems to invoke a sexual metaphor or perhaps one of human social relationship, but the reader needs more information to make use of such metaphors. An audience member would be obliged to look for more instances of "leptoquark" as a possible target domain, and "coupling" as a possible source, and thus to see what other, more comprehensible terms or information are associated. This co-location approach is laborious, unlikely for a science audience, and therefore such a metaphor will not fulfil its function of making the scientific subject matter convenient to understand.

But something similar has been used in scholarly lexical analysis where the target domain is not a thing, substance or object, but a process, or where many conceptual metaphors are simultaneously employed, and the lexical instantiations of target and sources are not co-located; machine searches for source domain key words produce clusters, suggesting target domains of interest (Lederer, 2016). Sometimes the target domain of metaphorical language is not just obscure, but absent. It is not unusual to find metaphors in poetry or allegorical prose where no target domain is explicitly instantiated. Kövecses (2002, p. 45) illustrates this with a poem by Emily Dickenson where several conventional metaphor source terms describing love are found in combination, the target is never named but the audience assumed able to make sense of what is said; science writings are very unlikely to rely so much on an audience's inferential powers. Consequently, many authors in this volume take pains to familiarize the audience with the nature of likely unfamiliar target domains before presenting scientific metaphors.

3.2.5 *Abstract source domains*

Our review of the central tenets of CMT, above, presumed that a source domain-to-target domain mapping involved a source domain that is concrete or more familiar and a target domain more abstract, complex or unfamiliar. What happens if a metaphor source domain is not actually concrete, but instead the language used is abstract, perhaps vague? If a metaphor fails to evoke a reliable experiential gestalt shared by science communicator and audience, the structure of the source domain (not only which elements are included in the source domain, but also their interrelationships), and the semantic network in which it is embedded, will not reliably be mapped to the target. If the source domain is not properly understood or even familiar, misunderstanding or misinterpretation occurs (Cameron, 2003).

Such instances may involve a reversal of the more common relationship found with conceptual metaphors as mentioned above, that is, where the source domain is structured by concrete sensory or socio-cultural experience in order to facilitate understanding of a more abstract target domain (Gentner, 1982; Kövecses, 2005; Lakoff, 1993, p. 229). In science and, in particular, the scientific topics reviewed in this volume, this reversal can sometimes be found. Metaphor source domains might be said to exist on a continuum of abstraction (Borghi & Binkofski, 2015) such that, to varying degrees, audience members lack grounding of some metaphors in actual experience.

If the goal is to enhance access to the scientific topic, and if abstract source domains are somehow necessary or unavoidable (such as when specialized models or mathematics is used), the science communicator is obliged to give special emphasis to context and background information. Failing this, where an audience has been insufficiently exposed to source domain structure or has learned only abstract principles, the features of the source domain remain unknown and can't readily be aligned and mapped to the target. Deliberate review of the correspondences between source and target, sometimes attempted in school situations, can help.

Note how mathematics teachers attempt to assist this alignment process in teaching the balancing of equations by introducing the analogy of an actual balance scale ("balancing equations is like balancing a scale," Richland et al., 2007, p. 1128); students learned better when the teacher manipulated the scale and pointed out the correspondences between source domain (balance scale) and the target domain (algebraic equation) with gestures and explanations. This illustrates how cognitive processing demands might be reduced, requiring less struggle as students search long-term memory regarding the source domain and keep mapped features in working memory while attempting to understand (Richland et al., 2007). Additional insights about conceptual access to abstract source domains comes from neurological evidence that not only conventional and concrete source domains may reactivate embodied sensorimotor simulations (as mentioned above), but that abstract concepts can do so as well (see Jamrozik et al., 2016).

3.2.6 *Metaphors in combination*

For an unfamiliar topic or target domain, not one, but multiple metaphor source domains are likely to be required in order to cover all important facets. The shift in metaphor research methodology to corpora analysis makes it easier to study how conceptual metaphors, rather than employed singly, actually are used in combinations. Each separate metaphor contributes to some understanding and none alone is sufficient. Metaphor structure, and thus comprehension, can be significantly altered in such cases. For example, conventional but conceptually distinct metaphors (ORGANIZATION IS PHYSICAL STRUCTURE and THE STATE IS A FAMILY) are found to serve especially well in explaining politics (Perrez & Reuchamps, 2015). But how might they relate not only to the target domain, but to each other? Chapters in this volume report various ways that scientific metaphors are used together.

Of importance to conceptual metaphor scholars are such matters as how combinations of metaphors could produce novel forms (Lakoff & Turner, 1989). Some metaphor combinations include background metaphors, necessary for understanding but not dominant (Blumenberg & Savage, 2010). Primitive or primary metaphors that complement each other can combine into complex ones (Grady, 1997; Lakoff & Johnson, 1999; also see Smith, 2009), form compounds of primary and cultural metaphor, metonymy, and literal propositions (Yu, 2008), or consist of a core metaphor with conceptually integrated sub-mappings (Veale & Keane, 1992). There may be scenarios or mini-narratives (Musolff, 2006), clusters or chains in text (Koller, 2003), with elements that range from fully consistent to semantically divergent and clashing (Charteris-Black, 2005). Two or more source domains may interact or blend (Fauconnier & Turner, 2002) or form hybrids in film or photo to serve explanatory purposes (Forceville, 2016).

When an explicit scientific analogy is chosen, it is not simply to change point of view or introduce an unfamiliar perspective, but to instruct students on a science subject that may be complex and multi-faceted. For example, to explicate the catharsis theory of aggression a psychology professor metaphorically uses an overarching conceptual metaphor, AGGRESSION IS FLUID IN A CONTAINER, then elaborates this into an analogy using additional direct metaphors that realize sub-mappings such as AGGRESSIVE IMPULSES ARE DROPS OF WATER ENTERING A TANK and AGGRESSIVE IMPULSIVITY IS WEIGHT/PRESSURE OF WATER BUILDING UP IN TANK, then extending the analogy further with other direct and indirect metaphors that are conceptually coherent (Beger, 2011). But this analogical explanation omits the use of (other) conventional metaphors for aggression such as HEAT, and literal accounts of aggression such as attitudes or emotional instability. So the professor has chosen a conceptually coherent combination of metaphors to best enable students to think through the chosen theory, postponing more comprehensive and accurate understanding. This book illustrates numerous other ways that instructional analogies, involving combinations of direct and indirect metaphors, trade scientific accuracy for coherence of understanding.

Gibbs (2016) brings together many points of view regarding combinations of metaphors, showing that cultural knowledge, assumptions, beliefs, reasoning, ancillary knowledge, and multi-model mixes are all important. Despite the potential for interference or confusion, multiple metaphors in combination do regularly operate successfully without clashes of meanings or images. This has inspired others to investigate how metaphors are activated in particular contexts, for example, how juxtaposing multiple, conceptually clashing source domains makes one of them more important or salient than another (Gibbs, 2017), how various signals such as "figuratively speaking …", hedges ("kind of", "if you will"), and "scare" quotes direct audience attention while mixed metaphors set up deliberate contrasts between conceptually disparate source domains (Nacey, 2013). In this volume, we see numerous examples of these metaphor combinations that appear to re-conceptualize, recontextualize, or produce alternative perspectives on a topic.

So far, we have seen that both the linguistic and the conceptual functions of metaphor are important for the conduct, description and explanation of science. However, there is another level at which metaphor operates, the *discourse function* or *metaphor in communication*. Above (3.1), we pointed out that metaphor in language is largely concerned with its linguistic form or conventionality, which can have effects on how the metaphor is processed during online comprehension. In the present section, we drew attention to the conceptual structure or metaphor in thought, pointing out the importance of mappings and differences of various types of source domains which provide rich knowledge to be made use of when communicating science. The next Section (3.3) considers a metaphor in its discourse context and asks how a given metaphor is supposed to operate in science communication. For instance, is the metaphor intended to *explain* a scientific aspect or is it perhaps used in order to shift the audience's attitude towards a scientific phenomenon and thereby be *persuasive*?

3.3 Metaphor in communication – the discourse function

Over the last twenty years, metaphor scholarship shifted to a more discourse-based methodology, which makes it possible to document in more detail the particular forms and meanings that metaphors take in authentic communicative situations. This approach has revealed variations not so apparent when the process of metaphor conceptualization focused primarily on isolated examples. More attention has therefore been brought to metaphor's communicative function.

Metaphor starts by sharing the communicative functions of language generally, such as expressing facts, opinions, theories, the truth or falsity of propositions and logic. Also like other forms of language, metaphor will provide contextual frames, attract attention, express emotions, evaluate, motivate and inspire. As figurative language, metaphors have long been viewed as communications tools, even when primarily seen as adornments or embellishments to literal language. They can make a difficult topic easier, aid memory, and draw attention to key aspects of the subject matter or target domain. Being more compact, metaphors often provide a means to communicate quickly and efficiently compared with literal language. They can express phenomenal experience that may be inexpressible literally (e.g., scientifically unobservable phenomena such as subjective mental states are often depicted as things that move the body, pressing or pulling: THOUGHTS ARE OBJECTS THAT PASS THROUGH SPACE, EXERT FORCE). They liven up the communication, do so richly, vividly and clearly (Gibbs, 1994), giving metaphor "an indispensable communicative function" (Ortony & Fainsilber, 1987, p. 183).

When metaphors are considered in context, rather than being isolated, the Wittgensteinian notion of "meaning as use" (Määttänen, 2005), when applied to scientific metaphor, asserts that the science writer communicates purposefully to achieve an intended effect, including any or all of the communicative outcomes just mentioned in the preceding paragraph, in the particular setting and context. A proper theory of metaphor, especially a cognitive linguistic one, must provide insight into the communicative dimension of metaphor. Thus, it is not surprising that Steen (2008) proposes an enriched model of metaphor by explicitly incorporating the communicative function. A review of communicative functions that inevitably emerge from our earlier theoretical discussions of CMT (2.1), metaphor in language (3.1), and metaphor in thought (3.2) is appropriate before continuing.

3.3.1 *Review of metaphor in communication as implied in theoretical discussions above*

Although Conceptual Metaphor Theory (CMT) does not explicitly state a communicative function for metaphor, it defines metaphoricity as the information transfer from source to target domains via correspondence mappings. Conditions for successful mappings are explored. Anyone interested in enhancing the communicative potential of metaphor will attend to these conditions so as to afford systematic inference structure to assist the audience's reasoning. Investigations stimulated by CMT into correspondences that map or fail to map, and into the possibility of category formation as an alternative explanation, lead in turn to the Career of Metaphor formulation. This gave insight into problems in understanding scientific and other concepts that depend on a metaphor's more frequent use and declining novelty over time. It led to strong lessons for when and how metaphor might best be communicated to a given audience and misleading inferences avoided.

In discussing the language function of metaphor, the distinction between conventional and novel metaphors highlights communication issues. Conventional metaphors are used unconsciously but nonetheless frame the communication of scientific descriptions and explanations. Novel metaphors more explicitly communicate source domain features intended to educate the audience. Further work by metaphor researchers to understand the Career of Metaphor prompts science communicators to know where in its career a chosen metaphor is, its frequency of use and status among specialists as a theory constitutive construct that might stimulate new hypotheses or become a conventionalized term. By observing this, one can tailor communication to either close access to the source domain by essentially ignoring its structure and treating it as a literal, technical term, or foregrounding the source domain if the audience can benefit from further explanation of the scientific phenomenon. Using similes and analogies prompts audience attention to the mappings of source domains to targets in order to have a stronger impact on reasoning. From this, science communicators learn that the wrong choice of metaphor can communicate unintended interpretations. This, in turn can motivate them to make intentional or deliberate choices.

Understanding of the conceptual function of metaphor was shown above to benefit from more rigorous methodologies. Corpus and discourse analysis methods reveal details of metaphor forms in actual language and this is helpful in sensitizing science communicators to ever-present conventional metaphors alone and in combinations, the ways they nest together or form hierarchies, blend, mix in narratives, and the effects of multi-modal combinations found in advertising and instructional material. Varied examples of both embodied and social metaphors were supplied by the more comprehensive discourse-based methodologies. Science communicators, when consciously choosing a metaphor or simile, will naturally want it to be salient. They may enhance saliency by extending similes into analogies that highlight structural aspects of a source domain and promote better cognitive alignment with the target. The study of saliency shows the importance of contextual and cultural knowledge, assumptions and beliefs. This includes target and source background knowledge an audience must possess to put a metaphor "foremost in our mind," easily accessed mentally, readily activated and mapped to the target domain. Multiple metaphors in combination, despite the potential for interference or confusion, are seen in actual discourse to regularly operate successfully. Such real-life examples show what might be specially created in science writing and other genres to communicate science.

Of interest are the purposes that science communicators have in mind when they use particular metaphors. For instance, in science pedagogy, metaphors might be chosen in order to *explain* a scientific concept whereas in science popularization, we might find more diverse reasons to choose certain metaphors, such as *convincing* the public or *evaluating* a scientific concept. Add to this an intention to shift perspective, contribute theory-constitutive structure, or simply to draw attention, persuade, convince, promote ideological agendas or propagandize.

We can see, then, that scholarly work concentrating on CMT, language and the conceptual structure of metaphor have brought forth communicatively relevant factors in metaphor use. Knowing in more detail how metaphor actually occurs in discourse allows its communicative efficacy to be evaluated. What particularly stands out is the importance of deliberation, awareness or consciousness in influencing choices in metaphor use. So the elevation of *communication* as a third fundamental function of metaphor, and a focus on *deliberate metaphor*, seem to be natural outcomes of these developments.

Steen's recognition of the communicative function of metaphor (e.g., 2008, 2010, 2015) focuses on a distinction between 'deliberate' and 'non-deliberate' metaphor and this has generated considerable discussion and controversy. In the following sub-sections, we will first briefly outline his notion of 'deliberate metaphor' (3.3.2) and then we will point out difficulties with this concept and cite alternatives (3.3.3).

3.3.2 *The concept of 'deliberate metaphor'*

The value of deliberate metaphor in communication has been studied and partially confirmed by Beger (2019) and Reijnierse (2017), who applied improved methods of distinguishing potentially deliberate metaphors from non-deliberate ones. Their studies show that deliberate metaphors are important tools for shifting an audience's perspective to accord more to that of the metaphor's source domain. The effectiveness of this perspective-changing function of deliberate metaphor depends on the particular context and purposes of the participants of a given genre or sub-genre. For the genre of science pedagogy in particular, Beger (2019) shows that deliberate metaphor fulfills important explanatory, but also affective, functions in college science lectures despite certain limitations and problems.

Steen adds the communicative function of metaphor (e.g., 2008, 2010, 2015, 2017a) to CMT's existing two-dimensional (language and thought) model of metaphor. In so doing he emphasizes 'deliberate metaphor', distinguishing it from 'non-deliberate' metaphor in communication in a binary fashion, so every metaphor is seen as either deliberate or non-deliberate. A deliberate metaphor is said to show evidence of a writer or speaker's attention to and, in turn, draws audiences' attention to the metaphor's source domain (see, e.g., Steen, 2017b, pp. 281–284). Some of the types of metaphors we outlined above (3.1) almost automatically fall into the category of deliberate metaphors, according to Steen's definition. If a metaphor is novel for a particular addressee (see 3.1.1), for instance, he or she will probably have to attend to its source domain in order to make sense of the metaphor in its context. Other types of metaphors that seem to require attention to their source domain due to their linguistic form are similes, analogies or other forms of metaphorical comparisons (see 3.1.2). Since these types of metaphors involve explicit comparisons between the source and the target domain, the source domain has to be attended to in order to resolve these comparisons (cf. Steen, 2010, p. 56).[7] Other types of metaphors (conventional ones, for instance) can, of course, also be used in such a way that they require attention to the source domain and would hence be classified as deliberate metaphors in Steen's model. However, they do not simply draw attention to their source domains by themselves. Some other linguistic or contextual features would be required.

One of Steen's central arguments is that attention to the source domain gives deliberate metaphors a clear communicative function. Yet he states this attention may or may not be conscious on the part of the language user (see, e.g., Steen, 2015, p. 69). Many readers may now wonder how a person can pay attention to a metaphor's source domain without being conscious of it. This seems contrary to the very notion of 'deliberate metaphor' and furthermore implies that 'non-deliberate metaphor' requires no attention and thus lacks any communicative function. So, by this account, the binary distinction between deliberate and non-deliberate metaphor would relegate the bulk of all metaphors in language – non-deliberate metaphors – inferior to the relatively small group of deliberate metaphors. Problems like these lead us to our brief discussion of difficulties with the concept

7. Note that in his model of metaphor, Steen (e.g., 2010) subsumes similes, analogies, and other forms of longer metaphorical comparisons under the label 'direct metaphor'. However, since this label is less informative than naming the tropes (e.g., *simile* or *analogy*) and not of importance for the contributions in this volume, we will refrain from outlining Steen's distinction between 'direct' and 'indirect' metaphors. The interested reader is referred to Beger (2019, Chapter 2.2.1) for a summary and critical discussion of this binary distinction made by Steen.

of deliberate metaphor and alternative approaches to discourse or communicative functions of metaphors.

3.3.3 *Problems with 'deliberate metaphor' and alternative concepts*

Besides a lack of empirical evidence that audiences actually attend more to the source domain of so-called deliberate metaphors (Gibbs, 2015), in science communication a given metaphor is not necessarily either deliberate or non-deliberate. As we explained above (3.1.1), metaphors that are quite conventionalized among specialists of a scientific discipline, that is, no longer considered metaphorical, might be completely novel for non-specialists or novices in the scientific field. When an audience perceives a metaphor as novel, it inevitably attends to the source domain, which (by Steen's account) turns that metaphor into a deliberate one. Thus, any given technical term in science communication based on a conventional metaphor might be both a *non-deliberate* metaphor (for specialists in that scientific community) and a *deliberate* one (for non-specialists).[8] Furthermore, especially with metaphorical technical terms, non-specialist audiences of science popularization may gradually become familiar with the metaphors of the respective discipline. Therefore, any given metaphor can potentially change from being deliberate for an individual to becoming non-deliberate to that individual over the course of a discourse event. We see, then, that Steen's concept of 'deliberate metaphor' – a concept that is supposed to elucidate a metaphor's communicative function – can account neither for individual differences among discourse participants nor for the dynamics of discourse events.

However, alternative approaches exist that can help. One of them is Müller's 'dynamic view of metaphoricity' (Müller, 2008, 2017), which is in line with the dynamical systems approach to metaphor by Cameron and Gibbs (Cameron, 2010a, b; Gibbs & Cameron, 2008). In this approach, metaphoricity "is activated dynamically in an interaction – over the course of a discourse event and to varying degrees" (Müller, 2017, p. 300). Since metaphor activation is described as quite similar to 'deliberateness', that is, "putting metaphoric meaning into the foreground of attention", Müller's dynamic view might be able to retain the advantages of Steen's concept of 'deliberate metaphor' (recognizing that metaphors can in fact draw attention to their source domain but often are not used in that way) while disposing of the difficulties described above.

Charteris-Black (2012) also takes issue with Steen and introduces the notion of 'purposeful metaphor'. This notion is not connected to aspects of metaphor processing such as attention but instead considers three important aspects of

8. See Beger (2019) for discussions of specific examples of such cases, for instance in Molecular Biology lectures.

metaphor in discourse: a metaphor's "intention or idea, metaphor use or plan, and rhetorical outcome or social impact" (Charteris-Black, 2012, p. 19).

Additional examples of metaphoric communications in science can be found that raise difficulty with Steen's strict definitions of 'deliberate metaphor.' Consider some, initially introduced as novel labels drawing attention to a source domain and provoking cross-domain mapping, then used casually and non-deliberately once they become familiar. As conventional, indirect metaphors, used repetitively, consider the degree to which these familiar usages channel thinking: genetic "blueprints," ecological "footprints," "self-regulating" systems, "invasive" species, "agents" of infectious disease, "superbugs," "arms races," or "food chains". These deeply entrenched indirect metaphors make complex scientific topics simpler by seeming to encapsulate obvious qualities of the target domain while at the same time they are *ideological*, *constraining* of new thinking, and quickly debunked by current science (Taylor & Dewsbury, 2018). Referring to certain parts of a city as "urban blight" versus "urban communities" encodes a stereotypic notion that organizes information and attracts attention to different aspects of a problematic situation: tear down and replace vs. nourish, reinforce and strengthen (Schön & Rein, 1994). When such generative metaphoric terms become popular and conventional they contribute more to ideology than science.

But the impact of such examples cannot be known until we see how they are deployed in context; in the professor's lecture example, above (Beger, 2011), such terse, indirect metaphoric labels and terms had been deliberately introduced in combination with a direct, deliberate, overarching metaphor, producing a multifaceted analogy that works to explain scientific theory (especially in a lecture format where their effect can be evaluated and adjusted in real time).

Interestingly, relatively subtle exposure to alternative metaphors may weaken these entrenched concepts. Numerous psycholinguistic studies prime subjects with unexpected metaphoric phrases, give no guidance on interpretation, then find improved comprehension of related discourse and notable shifts from entrenched framing (see, for example, Patterson, 2017). Exposure to comparatively complex metaphoric frames likewise induces shifts away from simplistic points of view (Thibodeau et al., 2016).

So we see that understanding "deliberate metaphor" may not involve anything new that metaphor scholars have not already taken into account. We might therefore wonder if we need any particular name or concept for a "special" type of metaphor, including "deliberate metaphor," in discourse or communication. Perhaps we can perfectly well analyze various aspects of a metaphor's discourse or communicative function in science with what we already know at the level of language and conceptualization as summarized at the beginning of this section. Readers of this volume will find contributions that reveal discourse or communicative functions of metaphors, including science communicators' purposefulness in selecting certain metaphors, but without introducing a new 'type' of metaphor to do so.

After considering the pluses and minuses of 'deliberate metaphor' regarding a metaphor's communicative function we see some value in applying this concept in cases where prime examples of deliberate metaphor occur. However, communicative or discourse functions of metaphor in science conduct and science communication can be analyzed in most cases without invoking this notion and simply using the tools metaphor scholarship already provides, such as distinguishing novel from conventional metaphor, identifying similes and analogies, knowing the scientific knowledge of participants and of a metaphor's general purpose. The various chapters of this volume will illustrate this point.

4. Organization of this volume

It is because of the theoretical and methodological shifts in metaphor studies reviewed here, with the resulting potential to make science more accessible, that we present this volume. We offer overviews of metaphor in broad scientific fields (natural science and social science) and address the functions of metaphor in specific scientific fields for different audiences (cell, marine, and human reproductive biology, thermodynamics, cognitive psychology, criminology).

This volume also includes a study of multi-modal (visual and auditory) aspects of scientific metaphor – a rather neglected aspect in conducting and disseminating science. Taken together the chapters look at how metaphors guide scientific observations, help develop theory and form hypothesis, as well as structuring science pedagogy, all of which will hopefully improve metaphor applications in science. All chapters are prepared not only for metaphor specialists but also with an eye towards practicality that will make this volume valuable to non-linguists, including practicing scientists, historians or philosophers of science, teachers at all levels, and journalists. This leads us to a short summary of chapters, together with the overall organization of this edited volume.

The volume's **first part** provides an overview of the role of metaphor in natural science. First, **Theodore Brown** demonstrates in **Chapter 2** how three overarching social metaphors – the Semiotic Metaphor, Teleology, and Emergence/Supervenience – are used extensively as well as systematically in the study of cellular systems in biology. Operating within the framework of Conceptual Metaphor Theory (CMT), Brown illustrates how the conceptual metaphors BIOLOGICAL PROCESSES ARE COMMUNICATION and CAUSATION IS ACTION TO ACHIEVE A PURPOSE guide scientists from observations to robust theories. Instances of these conceptual metaphors are widely employed when scientists reason about observations, form hypotheses, and generate ideas for new experiments. While the focus of this chapter is on scientists' acquisition and evaluation of new knowledge, Brown also argues that understanding the role of metaphor in these fundamental scientific processes is paramount for teaching science. Furthermore, he points to the value of deliberate metaphor in science pedagogy, for instance, when teachers adapt their explanations to different levels of knowledge on the part of their audience, or when they compare alternative metaphorical models for the same scientific concept.

Whereas Chapter 2 emphasizes the *social* grounding of metaphors in science, **Chapter 3** focuses on embodiment in the sense of scientific metaphors' grounding in our *sensorimotor* experience. **Tamer Amin**'s chapter examines the metaphorical construal of energy in the discourse of physics, thereby complementing Brown's study of metaphor in biology. Chapter 3 also adds another perspective on the concept of metaphor itself, as Amin analyzes the metaphorical construal of energy from the perspective of both CMT and Blending Theory (Fauconnier, 1996; Fauconnier & Turner, 2002). Amin brings together various studies in pedagogical settings, such as science lectures and science textbooks to illustrate the pervasiveness of metaphors used by experts. He also devotes his overview of metaphor in these genres to the students' understanding of energy. This allows Amin to draw conclusions about difficulties faced by learners in natural science education.

The **second part** of this volume complements the foregoing by considering metaphor use in the popularization of science. Concentrating on central concepts in biology and biochemistry, a more complete picture of the role of metaphor in science emerges. In **Chapter 4**, **Bettina Bock von Wülfingen** investigates how metaphors are used in German quality print media on reproductive technologies. Controversial discussion in German public discourse about the use of biotechnology in reproduction was initiated by the birth of the cloned sheep Dolly in 1997. The newspaper articles that Bock von Wülfingen collected for her corpus were published around the year 2000 when the discussion in Germany appeared to become more open to genetic technologies due to a change in political leadership. The then new German chancellor promoted Germany as an ideal location for biotechnology industries, signaling a more liberal and progressive stance towards new reproductive and genetic technologies. Bock von Wülfingen's linguistic data enables her to uncover how metaphors not only *educate* the public but also create future visions in order to *convince* the public, across the political spectrum, of the value of reproductive and genetic technologies. This chapter shows how metaphor can be used to change popular attitudes about a scientific topic in such a way as to persuade the public of its benefits.

In a similar vein, **Chapter 5** explores metaphors in press popularizations for the scientific concept apoptosis. **Julia Williams Camus** also critically examines the metaphors used in the newspaper articles of her corpus. The metaphors used are crucial for the public's understanding of apoptosis and its relation to cancer. However, unlike the preceding chapters whose metaphor analyses mainly focus on the conceptual function, Williams Camus draws attention to the linguistic realizations of metaphor. She applied the Metaphor Identification Procedure, MIP, (Pragglejaz Group, 2007) to her corpora of Spanish and English newspaper articles, which facilitates a detailed analysis of the metaphors' basic senses and mappings. She points out problematic representations of apoptosis that a combination of metaphors create in the media. Possible effects on the public's understanding are further examined by contrasting them with metaphors for apoptosis in specialized genres. Moreover, Williams Camus' comparison of Spanish and English newspapers points to differences and similarities in metaphors for apoptosis between the two languages. Chapter 5 ends with practical recommendations for science popularizers in order to help them avoid unintended and problematic representations.

Chapter 6 adds another important layer in investigating metaphor in science popularization: multimodal analysis. **José Manuel Ureña Gómez-Moreno** integrates verbal and nonverbal metaphor analysis for biological processes. While Ureña Gómez-Moreno's corpus includes both specialized and popular genres, the main part of Chapter 6 considers the popularization of biological concepts in the form of video clips from documentaries. The analysis of video clips accounts for textual, visual, and auditory (including sound/music) elements. In his analyses, Ureña Gómez-Moreno demonstrates how these different aspects of underlying metaphorical thought interact with one another. While some pictorial metaphors, for instance, are conventional and theory-constitutive, a number of multimodal metaphors are used deliberately for other discourse functions in science popularization, in particular for promotional ones in order to attract the audience. It is argued that in science popularization, these two functions can complement each other so that explanations of abstract concepts are delivered in an amusing and striking manner for the benefit of the nonprofessional audience.

The edited volume's **third part** accounts for metaphors in the social sciences and the humanities. Analogous to Chapter 2 on important conceptual metaphors in natural science, **Chapter 7** provides an overview of three influential conceptual metaphors in social science. **Thomas Smith** analyzes the conceptual metaphors SOCIAL PROCESS IS DATASET, SOCIAL PROCESS IS FIELD OF FORCES, and SOCIAL ENCOUNTER IS ADAPTIVE DYNAMICAL SYSTEM, along with their respective submappings, revealing a framework of the development of metaphors in social science. Based on his corpus of specialized social science discourse, Smith shows how metaphors first stimulate hypotheses, are then extended to account for results in successive rounds of observation and theory development, tracing the degree to which each metaphor is found useful and retained over the years. Chapter 7 concludes with a practical 'checklist' for scientists, science popularizers, and science teachers in which Smith suggests questions derived from his analyses that are meant to better guide research in the social sciences as well as to enrich the understanding of nonprofessional audiences.

Chapter 8 follows the path of a single, but quite complex metaphor in the social sciences/humanities. **Anke Beger** shows how the metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM was first established in specialist discourse to theorize about the human mind and brain. This metaphor constitutes a prime example of *deliberate metaphor* (Steen, 2015), which is first used by the philosopher John Searle, and later modified by other philosophers, to convince fellow academics of particular views on the mind. However, the main part of Chapter 8 examines a college professor's adaptations of the same metaphor in a philosophy lecture. In her discourse-based metaphor analysis, Beger demonstrates the difficulties faced by educators when trying to deconstruct the complexities of such deliberate metaphors in order to communicate different perspectives of philosophers to students. Beger shows that the philosophy professor in her data struggles with this task. This causes changes in the metaphor structure and consequent misrepresentations of the original argument among the philosophers. The analysis raises awareness of possible pitfalls in metaphor use in science pedagogy that educators should strive to avoid.

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PART I

Metaphor in natural science and science education – an overview

CHAPTER 2

Social metaphors in cellular and molecular biology

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Consistent with conceptual metaphor theory (CMT), metaphor use in biology is characterized by three overarching metaphorical themes: The Semiotic Metaphor, Teleology and Emergence/Supervenience. These themes are applied in analyzing metaphor use in the study of cellular systems. Use of metaphors drawn from social domains is extensive and systematic. In science teaching, attention should be paid to *how* scientists acquire and evaluate new knowledge, and convey new findings. *Abductive inference* as a means of arriving at a best explanation is of great pedagogical value. Abductive inference depends upon metaphors grounded in embodied and social conceptual frameworks. Explicit acknowledgment of metaphorical usage in science teaching illuminates the path from scientific observations toward robust theories.

Keywords: Conceptual Metaphor Theory, Semiotic Metaphor, Teleology, Emergence, complexity theory, supervenience, quorum sensing, deliberate metaphor, abductive inference, inference to the best explanation

Introduction

The fields of cellular and molecular biology are remarkable for the variety and complexity of the metaphors employed as explanatory devices in describing and explaining laboratory results. In the related domains of chemistry and biochemistry, explanatory metaphors are heavily drawn from the physical domains, and based on embodied conceptions of the world. By contrast, we find that in cellular and molecular biology, the explanatory metaphors are often based on experiences in social domains. I aim to show here that these facts are consistent with expectations based on Conceptual Metaphor Theory (CMT) (Lakoff & Johnson, 1980; Kövecses, 2010). As I illustrate in this essay, the uses of social metaphors in cellular and molecular biology are so numerous, interrelated and internally coherent as

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to constitute powerful evidence in their own right for the efficacy of CMT in accounting for metaphor production in this domain of science. To understand why this is the case we must begin with a general consideration of metaphors' roles in scientific practice.

Metaphors are essential features of scientific practice; they are not in the least optional or merely decorative. They permeate all aspects of science, ranging from observation, data acquisition and analysis, hypothesis formation, explanation, experimental design and theory formation to scientific communication at all levels. It behooves us then to ask what purposes they serve in all these varied activities.

Science can be described as the systematic acquisition of knowledge based on experimentation, hypothesis formation and observation. To practice science we must use our senses, and any extensions of them we may contrive in order to enlarge on our observational capacities. Secondly, we must describe and explain what has been observed. In broad terms, a good explanation is capable of accounting for many different phenomena using a restricted number of assertions as to their causes. The sciences involve special vocabularies, but in other respects, the explanatory language that scientists use to talk about their observations is not greatly different from that used in ordinary discourse. Metaphors often serve as explanatory devices in general discourse; similarly, the language of scientists is laden with metaphors.

Conceptual Metaphor theory (CMT) holds that our everyday speech reflects deep-seated conceptual understandings that derive from concrete experiences and feelings. The so-called conventional metaphors with which our everyday language is peppered are reflective both of physical experiences garnered from living in the world, and experiential gestalts that derive from social experiences and understandings.[1]

In their seminal book, *Metaphors We Live By*, George Lakoff and Mark Johnson devote an important section to *Indirect Understanding*.

> [W]e have seen throughout this work that many aspects of our experience cannot be clearly delineated in terms of the naturally emergent dimensions of our experience. This is typically the case for human emotions, abstract concepts, mental activity, time, work, human institutions, social practices, etc. and even for physical objects that have no inherent boundaries or orientations. Though most of these can be *experienced* directly, none of them can be fully comprehended on their own terms. Instead we must understand them in terms of other entities and experiences, typically other *kinds* of entities and experiences
>
> (Lakoff & Johnson, 1980, p. 171).

1. I will not attempt here a review of the theory of Conceptual Metaphor. See Lakoff, G. & Johnson, M. (1980), Kövecses, Z. (2010), and a brief account in Brown, T. L. (2003).

The situation described by Lakoff and Johnson is just the sort that occurs regularly in the everyday work of life scientists as they observe nature, whether it be at the macro level, as in observing the behavior of an animal, or at the micro level, as in following the growth of cell colonies or the changing concentrations of a particular molecule or group of molecules within a cell. CMT is key to understanding how the scientist is thinking; her aim is not merely to describe direct experience, but to provide a causal account of it. The scientist is in this way more or less forced to turn to a metaphorical description, one that gives form and direction to the account by calling upon experiences in domains far removed from the system under investigation. Very often the experiences most apropos are drawn from one or another aspect of human social life. Thus, experiential gestalts are commonly employed (Lakoff, & Johnson, 1980, Chapter 15). The vast number of examples of such metaphors, and the details of these metaphorical mappings in science, represents a powerful argument in support of the tenets of CMT, the most central of which are:

- metaphors are matters of thought, not merely of language.
- we employ inference patterns from one conceptual domain of thought to reason about another domain.
- the systematic correspondences we establish across domains are metaphorical mappings, which are shaped and constrained by our bodily and social experiences in the world.

Conceptual metaphor theory has been spectacularly successful in revealing how a host of abstract ideas dealt with in daily life, such as time, love, inflation or marriage, are conceptualized in terms drawn from our direct physical *and* social experiences. Lakoff and Johnson give the example of how we think and speak about the idea of LOVE:

> Certain concepts are structured almost entirely metaphorically. The concept LOVE, for example, is structured mostly in metaphorical terms: LOVE IS A JOURNEY, LOVE IS A PATIENT, LOVE IS A PHYSICAL FORCE, LOVE IS MADNESS, LOVE IS WAR, etc. (Lakoff & Johnson, 1980: p. 85)[2]

The complexity inherent in a complicated emotion and state of being such as romantic love cannot be captured adequately by the core, subconscious concepts derived solely from direct physical experience. More complex and nuanced conceptual frameworks needed are derived from our ability to recognize *whole patterns* in our experiences of daily life; for example, that of a journey. Two people in love might be spoken of as taking a journey together, one that follows over

2. We adhere to the common convention of using caps to denote conceptual metaphors. They typically apply to a broad range of specific instantiations of the primary metaphor.

time along a certain pathway, in which there might be ups and downs, filled with destinations, and events in which planning ahead might be a good idea, and so on. Thus, our everyday language dealing with romantic love is heavily sprinkled with what Lakoff and Johnson term *conventional metaphors,* examples such as:

> We'll just have to *go* our separate *ways*.
> Those two have *come a long way* together.
> They've been married now for 40 years; at times the *road* has been a bit *bumpy*.
> Our love affair is *on the rocks*.
> This relationship has *gone way off course*.
> I've fallen in love, but we seem to be *going in different directions*.

All of these expressions are instances of conventional metaphors based on the conceptual metaphor, LOVE IS A JOURNEY. The referents for these metaphors are *experiential gestalts*, basic units of perception in which a collection of physical and social experiences together form a set of related elements. Johnson (1987) discusses the *image schema* as a recurring structure arising from cognitive processes which establish patterns of understanding and reasoning. Image schemas are formed by a complex of bodily interactions, linguistic experience, and learned content (ibid.) and often form the basis of more complex conceptual metaphors, such as LOVE IS A JOURNEY, where the PATH-GOAL schema underlies the more elaborate domain JOURNEY. The conceptual metaphor LOVE IS A JOURNEY is more complex than an image schema as it involves mapping aspects of widely experienced experiential gestalts, journeys, which have both physical and social components, onto the intensely social experience of love.

Conventional metaphors that abound in everyday speech are used in science in much the same ways as in other areas of discourse. But, importantly, scientific discourse is permeated with the use of metaphors created to aid in describing and explaining new observations. We begin with a few comments on characteristic features of explanation in biology.

Over-arching metaphors in biology

While biology is the study of living systems, the scientist utilizes knowledge of chemistry and physics to understand any living system. It is important to keep in mind the distinction between a living organism on the one hand, and the interactions of living organisms with inanimate matter on the other. The viability of a biological system depends on appropriate surroundings, and passage of matter and energy across interfaces the system establishes with the surroundings. However, it is not always clear where the boundary for a system of interest should be drawn.

Further, while an entity such as a cell can be said to live, the cell itself is packed with a host of molecules and subsystems that in themselves are not living. We need metaphors to describe the processes that make the cell a living thing that are more complex than we normally require to describe properties of the simpler components that lie within the cell.

Thus, for example, a cell is sometimes described metaphorically as a factory (described in more detail below) (Alberts, 1998; Brown, 2003, Chapter 8). The metaphor engages subsidiary metaphors involving transport, energy, quality control and others that map onto processes occurring within the cell. In this example and in countless others, scientists draw upon experiential gestalts drawn from everyday social life in interpreting what is going on at the molecular level within the cell.

Because of their complexity, the biological sciences present special challenges to anyone who seeks to comprehend the full range and nature of metaphorical usages. It is helpful to keep in mind three fundamental metaphorical constructs that are more or less constant features of scientific thought in this domain:

– The semiotic metaphor
– Teleology
– Emergence and Supervenience

Each of these constructs represents a general conceptual metaphor that is instantiated in a variety of ways, as will be evident in the discussions that follow.

The semiotic metaphor

The language of biological explanation is replete with references to communication, in systems ranging from groups of mammals to colonies of cells. At all levels of scale, for change to proceed in an orderly way, biological systems require communication – some form or other of signaling. Because signaling and communication are important aspects of human cultural life, the metaphors employed in biological explanation draw heavily from social aspects of human culture. For example, at the macro level scientists talk about the mating behaviors of birds in terms borrowed from human relationships. At a different level the social structure of a beehive is understood in terms appropriated from language describing human societies. At the molecular and cellular level we find heavy use of terms such as "the genetic code", "messenger RNA", and "cell signaling". These examples and a host of others fit within the framework of a general *semiotic metaphor*: BIOLOGICAL PROCESSES ARE COMMUNICATION. Not surprisingly, there is a substantial literature dealing with the various ramifications of biological communication; how it can be understood, and how we can talk about it (Emmeche & Hoffmeyer, 1991). I will be discussing several examples in what follows.

Teleology

Teleology, a conceptual metaphor with a long history, is of the form CAUSATION IS ACTION TO ACHIEVE A PURPOSE (Lakoff & Johnson, 1999, p. 217). Both Plato and Aristotle argued for the existence of a telos; that each process or change we see in nature is the result of some entity moving toward a natural end. They did not attribute these ends to some external agency such as a god, nor did they imagine that mental activity is inherent in things. Rather, the end of a thing is internal, a part of its essence. The Aristotelian idea that things have inherent natural ends, which he called final causes, persisted in the writings of medieval scholars. At times, their language was explicitly metaphorical, and even fanciful. The alchemist, for example, might attribute the reaction of an acid with a base to a desire of the two reagents to mate. But Francis Bacon, writing in the early decades of the seventeenth century, advocated an empirical, inductive approach that emphasized experimentation, from which he wished to exclude teleology; that is, any talk of final causes. Analytic philosophy was a dominant current of thought throughout most of the twentieth century, during which time most philosophers of science rejected leanings toward teleological explanations.

Teleology is traditionally thought of as the imputation of purpose and ends to the behavior of entities that we have no reason to expect should be capable of independent volitional action. Though it is a contested notion, teleology has long been a persistent feature of biological explanation (Mayr, 1992; Dawkins, 1986; Allen, 2009). The kinds of purposes we associate with a human's actions are often also attributed to the behaviors of mammals, birds and bees. For example, we talk of a bird pair working together to make a nest *for the purpose* of rearing young. More remarkably, though, *purposeful action* is spoken of as inherent in living organisms at *all* levels, from insects and plants to single-cell organisms. The advent of Darwinism stimulated wide-spread use of teleological language. Statements implying that *nature has goals*, for example, that the behavior of a species is motivated by a *drive for survival*, appear teleological. Darwin was accused of harboring such ideas, though in fact he abandoned literal teleological language soon after concluding that natural selection, blind to any purpose, is the dominant mechanism of evolutionary change. Here is Darwin on the subject in the first edition of *The Origin of Species:*

> [N]atural selection is daily and hourly scrutinizing throughout the world, every variation, even the slightest; rejecting that which is bad, preserving and adding up all that is good, silently and insensibly working … (Darwin, 1859, p. 84)

In later editions of *The Origins* Darwin inserted a prefatory phrase: "It may be metaphorically said …".

Not every philosopher of biology is convinced that teleological explanation is invalid. The philosophical arguments surrounding the status of teleology in natural selection in particular are many and varied (see the following section on Metaphor and Evolution). In what follows it will become clear that teleological forms of explanation are virtually ubiquitous in biological accounts, particularly as they apply to the world of microorganisms and other cellular level processes. Unless the context indicates a literal intent, they can be understood as generally unproblematic examples of conceptual metaphors.

Emergence and Supervenience

From the beginnings of Western science, scientists and philosophers who concerned themselves with living systems puzzled how the special properties of living systems could arise from the inanimate matter that constitutes them. *Vitalism* posited a primitive substance or principle abiding in the organism that guided the vital processes ranging from embryonic development through the life cycle. With the advent of modern science, and most especially from the nineteenth century forward, vitalism gave way to other attempts to account for vital processes in nature in terms of something irreducible. John Stewart Mill, for example, wrote:

> To whatever degree we might imagine our knowledge of the properties of the several ingredients of a living body to be extended and perfected, it is certain that no mere summing up of the separate actions of those elements will ever amount to the action of the living body itself (Mill, 1843, Chapter 6)

Mill was one of the early emergentists, those who believed complex physical and chemical processes could give rise to *emergent* properties not *a priori* predictable from the constituent components, and not reducible to them by the laws of chemistry and physics. From the perspective of CMT, emergence can be thought of as a form of container metaphor, in which new properties emerge in a container that holds (a) the constituent parts of a system, (b) the laws that govern their interactions and (c) just those properties of the constituent parts that are predictable from the laws of chemistry and physics. The emergent system in effect is a new, larger container. To quote John Holland, a contemporary pioneer of emergence theory:

> We are everywhere confronted with emergence in complex adaptive systems – ant colonies, networks of neurons, the immune system, the Internet, and the global economy, to name a few – where the behavior of the whole is much more complex than the behavior of the parts (Holland, 1998, p. 2)

Emergence theory fell out of favor with the advent of neo darwinism, with its emphasis on molecular genetics, which gave rise to strongly reductionist views of biology. It smacked of teleology at a time when any hint of it was regarded unfavorably, of vitalism in disguise. In recent decades, however, the development of complexity theory has given emergence a new lease on life (Deacon, 2013; Holland, 1998; Johnson, 2001; Lineweaver, Davies, & Ruse, 2013).

In complexity theory the dynamic interactions among many parts of a complex system are at times unpredictable, even though the system at all times behaves deterministically. Small changes in initial conditions, for example, may cause large changes in later behavior of the system. As an example, we can understand the physics and chemistry of a tropical storm, but what small, local event sets in motion formation of the storm in the first place, and determines its course?

The tropical storm example illustrates that emergence in complex systems is associated with processes of self-organization. Jeffrey Goldstein refers to emergence as "the arising of novel and coherent structures, patterns and properties during the process of self-organization in complex systems." (Goldstein, 1999). Note the use of the word *arising*. Emergence involves the formation of new and more complex properties, which are seen as higher level than those from which they emerge, consistent with the conceptual metaphor MORE ORGANIZED IS HIGHER. Goldstein lists several common characteristics of emergent systems: (1) radical novelty; features not previously observed in the system; (2) coherence or correlation (meaning integrated wholes that maintain themselves over some period of time); (3) presence of a global or macro "level" (i.e., there is some property of wholeness); (4) being the product of a dynamical process (it evolves over time); and (5) being "ostensive" (it can be perceived). In summary, one can state the conceptual metaphor for emergence as: EMERGENCE IS THE APPEARANCE IN A SYSTEM OF COMPLEXITY NOT POSSESSED BY, AND INDEPENDENT OF, THE COMPONENTS FROM WHICH IT IS FORMED.

Finally, the system evinces "supervenience", or downward causation. This means that higher levels of organization act causally on lower levels. The expression "downward causation" provides another example from CMT of an orientational metaphor. Levels of organization are categorized in terms of a vertical structure, with the most general at the highest levels, and supervening on those below it

An example credited to the famous psychobiologist R. W. Sperry, illustrates the foregoing descriptions of emergence and supervenience, albeit with respect to a system that owes its contents and structure to human agency (Sperry, 1991). Imagine a cart wheel rolling downhill. The cart wheel itself has properties emergent on its constituent parts, consisting of the rim, the axle, the spokes and so forth. That is, it owes its characteristic properties as a wheel to the manner in which the constituent parts are organized to make the whole. One can think of the cart wheel as an organization of matter at various levels, ranging at the lowest from the atoms and molecules upward to the parts that are wooden, or metallic. At a higher level, there are the various constituents in their recognizable forms. The highest level for our purposes is the wheel itself, which possesses physical properties that exist just because all the components form an organized whole. Those properties supervene on the lower level properties, in that they determine certain behaviors of the wheel that would not exist were it not for that organization. They are said to exert a "downward causation" on the components. When the wheel rolls down the hill, all of the components and all of the atoms and molecules of the wheel are subject to the event, which is possible only because of the supervening organization.

Metaphor and evolution

There is no subject in modern biology that can be talked about, explored or related to other topics in any depth without reference, direct or indirect, to evolution. The fact of biological evolution permeates all thoughts of biology. Yet, ironically, evolution is not a completely understood and agreed-upon subject, even by those who are steeped in biological understandings, to say nothing of those who view evolution as a challenge to their religious beliefs or cultural inclinations. The divergence of beliefs regarding evolution is evident in differing views of its teleological underpinnings. We could start in many places, but let's begin with someone of recent notoriety. Thomas Nagle is not convinced that there is a purely materialistic, reductionist pathway to eventually understanding what makes human beings thinkers. The blurb on his 2012 book jacket contains this bit of text:

> Since minds are features of biological systems that have developed through evolution, the standard materialist version of evolutionary biology is fundamentally incomplete. And the cosmological history that led to the origin of life and the coming into existence of the conditions for evolution cannot be a merely materialist history, either. An adequate conception of nature would have to explain the appearance in the universe of materially irreducible conscious minds, as such. (Nagle, 2012)

Nagle argues that there is something missing in the conventional model espoused by evolutionary biologists. He hypothesizes a "natural teleology", an internal logic in the world's workings that impels matter from inanimate to living, from simple toward the more complex, from mere chemistry to consciousness. In the short space of 144 pages he doesn't get very far toward explaining what this might be, but it is doubtful that a much longer book would mollify the likes of Richard Dawkins, Steven Pinker or Daniel Dennett, who firmly believe that nature has no goals, direction or inevitable outcome. To a man, they were scornful of Nagle's book, as were most other evolutionary biologists.

The use of teleological language is commonplace in the biological literature. It is tempting to think of evolution as a mechanism, as purposeful. But toward what purpose? Which variations are bad and which good? The criterion of importance for Darwin was fitness for survival. Fast forwarding to the present, in a recent issue of the journal *Science*, A. N. Burdett criticized the following passage from an earlier issue of the journal concerning the iridescent fruit of an herb: "The fruit's dazzling display may have evolved to capitalize on the birds' attraction to sparkly objects, or to trick them into eating something that looks like a blueberry without going to the trouble of actually making juicy flesh" (Burdett, 2012). Burdett pointed out that if our current understanding of biology is correct, nothing evolves to do a specific task; such intimations of purpose are fanciful at best.

It should not be surprising that Darwin and the author of the paper criticized by Burdett resorted to such teleological language; humans have been conditioned throughout evolutionary development to account for things that occur in the world in terms of causal agents. Each of us learns such accounting from our earliest personal experiences and the influences of human culture. Not surprisingly, causation is a key element in CMT. Lakoff and Johnson suggest that causation is best understood as an experiential gestalt, possessing multiple possible features and common to all human experience (Lakoff & Johnson, 1980, Chapter 14). Isn't it to be expected that natural selection might be interpreted in terms of progression toward some goal? As Bernd Rosslenbroich explains, it is difficult to expunge from the language of evolutionary biology terms that smack of "progress" (Rosslenbroich, 2006).

Many scientists interested in complexity theory believe that there exist natural processes that inevitably move nature toward more complex, self-sustaining reactions that in turn convert more primitive raw materials into increasingly complex structures. Stuart Kauffman aims to show that the transition from mere chemistry to something self-sustaining in its interactions with the surroundings is possible and in fact inevitable. He contends that complexity itself triggers self-organization, or what he calls "order for free". The operative conceptual metaphor is COMPLEXITY IS SPONTANEOUS MOVEMENT TOWARD SELF-ORGANIZATION. He argues that if enough different molecules pass a certain threshold of complexity, they begin to self-organize into a new entity – a living cell (Kauffman, 1996). Available energy, be it sunlight, thermal energy of the surroundings or some chemical process, drives simpler structures toward more complex ones.

In complexity theory there is no purpose or intent involved, no goal-directed activity. Self-organization just happens, consistently with the laws of physics and chemistry. But the metaphorical language employed in complexity theory as it applies to biology is imbued with sensibilities of progress, improvement and attainment of "higher" order, because that is the way we have learned to view the world. Metaphors frame the world in "as though" terms. In complexity theory it is "as though" there were a purposeful drive toward higher order. The theory is a prime example of how teleology works: self-organization is the result of random processes but we are conditioned by our evolutionary development to view change in terms of entrenched conceptual metaphors such as PROGRESS IS A JOURNEY AND CAUSATION IS PURPOSEFUL.

Social metaphors in biology

Social metaphors of the sort exemplified by a conceptual metaphor such as LOVE IS A JOURNEY are commonplace in biology because the subjects of study are so often diverse and complex. A rigorously reductionist approach cannot yield an adequate description of even the simplest organisms. The interactions between all the molecular-level components of even a single-cell organism are vast in number, and intertwined in ways that give rise to signature emergent properties not attributable to any particular piece of the whole. Modeling a biological system from a reductionist perspective, solely in terms of molecular level physical and chemical processes, would limit the scientist to a set of conceptual metaphors based upon embodied experiences with the physical world. But that metaphorical repertoire does not provide a sufficiently broad framework for understanding the ways in which the system's multiple components interrelate. To grasp the complexity of biological systems, the scientist is moved to employ metaphorical concepts commensurate with that complexity. These are found among experiential gestalts formed from everyday life experiences in the social world.

We are not surprised to find social metaphors regularly appearing in hypotheses and theories relating to the behaviors of creatures such as squirrels and birds. One can also imagine that the "waggle dance" of forager honeybees is a means of communicating between colony mates, or that worker ants communicate with, or induce behaviors in one another in various ways. It is less obvious that the properties of bacterial colonies observed through a microscope, or the plaque that forms on human teeth, or the film that repeatedly forms around the drain in a kitchen sink should bring to mind a social activity. Yet remarkably, metaphorical language couched in terms of social behavior observed in human society is ubiquitous in scientific literature dealing with the microbial fauna responsible for these processes. To provide an adequate understanding of these metaphors, we must know something about the properties of cells.

Cellular systems

Cells, as living entities, can be considered in terms of three broad categories: *structure*, *processes* and *communication*. Scientists reason about each of these aspects in terms of distinct sets of metaphors. In the domain of *structure*, the cell has a distinct boundary, defined by the cell membrane, and a variety of parts and internal structural elements. The metaphors employed in assigning functional roles to these structural elements are drawn from macroscopic experiences with structured entities such as walls, supporting structures such as pillars, containers of varying shapes, and so on.

Cellular *processes* involve a host of chemical reactions and coordinated movements. Some processes are continuous, others are turned on and off at appropriate stages in the life of the cell. Many occur entirely within the cell, others involve movements of materials through the cell wall. I have written elsewhere about the kinds of metaphors employed in conceptualizing and describing cellular processes (Brown, 2003, Chapter 8). Picturing the cell as a factory is a popular pedagogical device (for example, Cell as a Factory, 2015). Multiple input and output processes occur, raw materials are consumed, products are formed, quality control measures are exercised, and materials are transported from one place to another. The factory metaphor is not merely occasional bits of colorful language; it and similar metaphors constitute the lingua franca of cellular biology as pedagogical devices and in describing novel research results. To illustrate, the term "protein quality control in cells", which appeared in the scientific literature for the first time only in 1989, is now a commonplace. An internet search using the phrase as a search term yields upwards of twenty million results. It is important to emphasize that this metaphor has not thereby become "dead" in the literary sense. Productive scientific metaphors grow in usage as elaborations are added and experimental evidence leads to new instances in which the metaphor operates. Thus, it is continually being evaluated and reinterpreted in light of new observational results.

The third, and for our present interests most important, facet of cellular life is *communication*. Cells, of whatever kind, normally do not exist in isolation. Many of the processes that constitute the life of the cell occur in response to changes within the cell or outside in the surrounding medium. Cells affect one another by releasing chemicals into their environments, to be detected by other cells in the vicinity, or through detection of molecules in their environments. Such processes, involving small molecules such as hormones, are recognized as a form of intercellular communication, referred to as *cell signaling*.

As a productive general metaphor, cell signaling entails many questions that call for further experimentation. For example, if the communication involves release and detection of a small molecule, what key properties must the "messenger" molecule possess? What triggers its release? How is it detected by the receiving entity? What processes are involved in converting the signal represented by the messenger molecule into a particular kind of signal that has consequences inside the cell? In work for which he received the Nobel Prize in Physiology or Medicine in 1971, Earl Sutherland showed that communication *between* cells involves a molecule ("the first messenger") that is converted to a second signaling molecule that acts *inside* the cell ("the second messenger"). That very productive metaphorical model inspired the 1994 Nobel Prize winning discovery by Alfred Gilman and Martin Rodbell of a special group of proteins, called G-proteins, that act as signal transducers. They convert the first messenger signal at the cell surface into a second messenger signal inside the cell.

Cell signaling has become an important subject within molecular and cellular biology. In a myriad of contexts, scientists draw upon their knowledge of the macroscopic world of communication to explain aspects of the microscopic biological world. I want to focus here on a particularly illustrative case: the metaphors for communication between bacterial cells.

Bacteria

It has been only within the past few decades that humankind has become aware that microbes too small to be seen with the naked eye are everywhere about us. As Bonnie Bassler writes,

> They include archaea, fungi and protists, but overwhelmingly they are bacteria. For billions of years these invisible critters, our forefathers, have been shaping the Earth and making it a suitable place for us to live. Higher organisms – all plants, invertebrates (including insects), and vertebrates (including humans) – occupy only a sliver of the world. (Bassler, 2012, p. 67)

Bacteria are single-celled organisms of a particular kind called prokaryotic, which denotes that they do not contain a nucleus. By contrast, the cells of all multicellular organisms, the plants, animals and fungi, do contain a nucleus and are termed eukaryotic. The prokaryotes are much older in evolutionary terms than the eukaryotes. They have had to survive great changes in the planetary environment during their long existence (Woese, 1987).

Bacteria are typically only a few micrometers in length; ten thousand of them side by side might form a line about an inch in length. They were first observed by the Dutch microscopist Antonie van Leeuwenhoek in 1676, using a single-lens microscope of his own invention. During the nineteenth century Louis Pasteur, Robert Koch and others demonstrated that pathogenic bacteria were the causes of many diseases. There ensued a prolonged war against bacterial pathogens which continues unabated to this day.

What was lost sight of in the focus on bacteria as pathogens is that an enormously varied and numerous world of microorganisms, mostly bacteria, pervades the entire planet, far outnumbering all other forms of life. Bacteria provide essential functions to every other species. They have made themselves at home in every niche in nature, from the deepest oceans to the hot geysers of Yellowstone National Park. Water from Lake Whillans, which lies more than 2,000 feet below the West Antarctic Ice Sheet, recently was found to harbor abundant microbial life. Each human body contains within and on it ten times more microbial cells of many different kinds than human cells. There are thousands of different species of bacteria in the human gut, and about 700 in the human mouth.

Altogether these various microbial species constitute the *human microbiome* (Buckman, 2003; Institute of Medicine, 2013). Microbes, mostly bacterial, pervade every surface and cavity of our body, and are highly specialized in terms of their interactions with our human cells. For the most part, they are benign, serving a multitude of functions essential to our lives.

How do these simple single-cell organisms thrive in all these different environments, and exhibit capacities that one would expect only from more complex, multicellular organisms? As it turns out, the answers all tie to communication.

Quorum sensing

J. Woodland Hastings, an outstanding Harvard biochemist who died in 2014, devoted most of his scientific career to the study of *bioluminescence*, the emission of visible light, by creatures such as fireflies, jellyfish and bacteria. During the 1960s, Hastings and a coworker, Ken Nealson, studied a bioluminescent marine bacterium, *Alivibrio fischeri*, that floats freely in the ocean. In these circumstances, the bacteria do not emit a characteristic glow. However, in the shallow waters off the Hawaiian Islands they exist in a symbiotic relationship with the Hawaiian Bobtail Squid, *Euprymna scolopes*, which live in those waters. The Bobtail Squid has a special light organ in its mantle. Each evening the squid selectively takes *A. fischeri* into its light-producing organ, and in the process, their concentration is much increased. When the concentration has reached a certain critical level, the bacteria collectively emit a luminescent glow. But how could these simple, single-cell organisms sense when there is a sufficient concentration of their fellows in the surroundings for them to collectively begin to glow with a discernible brightness?

Hastings and Nealson postulated that individual bacteria continuously release a signaling substance into the surrounding medium (Nealson, Platt, & Hastings, 1970). When the concentration of bacteria grows larger, the concentration of the signaling substance in their environment also increases. They further postulated that the bacteria not only release the signaling substance, they also individually detect it. When the bacteria concentrated within the squid's light-producing organ detect that the concentration of the signaling substance in the organ has surpassed a certain threshold value, they collectively and simultaneously commence luminescing. The mechanism of communication between bacterial cells postulated by Hastings and Nealson that triggers luminescence eventually came to be called *quorum sensing*.

The quorum is a social construct with a long history in western culture. It can be roughly defined as the minimum number of members of a deliberative body necessary to conduct business. The most common rationale for a quorum is to prevent an unrepresentative action taken at the behest of an unduly small number of persons. Assuming the criteria are agreed upon, ascertainment of a quorum proceeds by a counting of persons and comparison with the number required, as set by the rules. Nealson, Platt and Hastings reasoned that the quorum criterion is necessary for *A. fischeri* because bioluminescence consumes considerable energy in each cell to generate the luminescent reaction. That energy would be wasted if the concentration of the bacteria were not high enough to produce sufficient overall brightness, determined by the needs of the host squid.

The quorum sensing proposal is a remarkable example of mapping what is arguably a fairly complex human social behavior onto a biological system. It could be stated as a conceptual metaphor of the form A COLONY OF *A. FISCHERI* IS A DELIBERATIVE BODY OF PEOPLE. Initially the model was widely thought to be too complex for the likes of a single cell organism. In spite of widespread skepticism, however, it prompted a search for the presumed messenger, or *autoinducer*, molecule. Ten years after Hastings and coworkers' initial proposal, the autoinducer through which *A. fischeri* communicate via quorum sensing was identified. The relationship between *A.Fischeri* and the Hawaiian Bobtail Squid is an example of *symbiosis*, defined loosely as a close and usually long term interaction between two unlike biological species. Most frequently, the interaction is mutualistic; that is, it is beneficial to both species, though in different ways. Application of the term symbiosis in biology is metaphorical; the word was first used in reference to people living together communally. Its use in the biological context is yet another example of metaphors drawn from the social domain that are mapped onto observations in the microscopic world.

The power of a conceptual metaphor is that it provides a model from which one can draw inferences. These in turn set the scientist in search of answers to new questions. For example, what advantages accrue to the bacteria by residence in the light-producing organ of the squid? One possible answer is, they get fed. Prompted by the metaphorical model the scientist can search out the pathways and details of how the squid provides metabolic energy for the bacteria in the light organ. But what in this arrangement works to the benefit of the squid? The metaphor of symbiosis leads the scientist to reason that the luminescence provides protection from predators. Detailed studies have revealed that when the bacteria luminesce during the night, while the squid are active, their emitted light, radiated downwards, matches the moonlight level, and thus masks the squid's shadow from predators and prey, which lie below. The symbiotic relationship between *A.Fischeri* and the squid is a product of many evolutionary adaptations. The model that neatly accounts for all of the observations together is a beautifully coherent collection of social metaphors.

For nearly twenty years the system of *A. fischeri* and its interactions with the Hawaiian Bobtail Squib, and one or two others, were regarded as rare examples of quorum sensing. More recently it has become clear that quorum sensing is a fundamental feature of the microbial world (Antunes & Ferriera, 2009; Bassler & Losick, 2006; Gray, 1997; Greenberg, 1997; Lerat & Moran, 2004). We know now that it is the single most powerful tool that enables bacteria to rise above their status as single cell organisms and develop a broad repertoire of behaviors. The language scientists use to describe quorum sensing, and multiple embellishments of the initial idea, is rich in metaphors dealing with communication, but it also incorporates other concepts drawn from human social behavior, such as "public goods", "cooperativity", "cheating" and "vigilance" (Drescher, Nadell, Stone, Wingren, & Bassler, 2014). To illustrate the range and importance of the metaphors employed, I discuss two quite striking examples of quorum sensing. But first, we need to see how cooperation is understood to work in cellular and molecular systems.

Cooperation

The concept of cooperation is central to understanding the behaviors of biological systems at all levels, from assemblies of single cell organisms to human societies. As applied to human behavior the standard dictionary definition might be: Cooperation is common effort or the association of persons for common benefit. Cooperation can be viewed also in the world of plants and microscopic organisms, as via the conceptual metaphor CONCERTED CAUSAL ACTION IS COOPERATION. Consider an example from the world of plants in which the components are as devoid of conscious intent or purpose as could be imagined (Denison & Muller, 2016).

Most plant species depend on bacteria called rhizobia that grow symbiotically as nodules on the plant's roots. The rhizobia help the plant acquire nutrients, such as phosphorus and nitrogen, which it would not otherwise be able to assimilate. The plant-rhizobium relationship is symbiotic, in that the rhizobia depend on the plant to provide energy-rich molecules they need to grow and reproduce, and the rhizobia supply the plant with otherwise inaccessible minerals: a clear case of cooperation (Tiers, Rousseau, West, & Denison, 2003).

Although the word symbiosis, derived from the Greek language, means to live together, in biology symbiosis usually is taken to mean something more: a relationship of mutual benefit or dependence. We humans tend to think of such relationships in teleological terms. It turns out that each plant hosts several different strains of rhizobia as nodules on its roots. Each strain divides its resources between supporting its own reproduction and contributing to the "public good" of host-plant vitality.

This sets up the possibility that a particular strain of rhizobia could "cheat", by diverting excessive resources to its own reproduction, and thus outcompete other strains. This is where the concept of supervenience comes into play. Experimental studies have demonstrated that plants have evolved ways to prevent this sort of one-way resource grab. They can shut off the oxygen supply to that nodule, and thus limit its capacity to reproduce. That is to say, plants can supervene on their bacterial symbionts by sensing the activities of the bacteria. They can "impose sanctions" by limiting the supply of energy in the form of molecular food to nodules that supply them with insufficient nutrients.

The following sentences from the abstract of a paper by Tiers and colleagues illustrate the pervasiveness of conceptual metaphors such as: EXCESS CONSUMPTION OF RESOURCES BY A SYMBIONT IS CHEATING and HOST RESPONSE TO NUTRIENT LOSS IS PENALIZING CHEATERS. Note also that the abstract supplies several examples of supervenience, in the form of metaphorically PURPOSEFUL ACTIONS: monitoring, penalizing, and stabilizing:

> Explaining mutualistic cooperation between species remains one of the greatest problems for evolutionary biology. Why do symbionts provide costly services to a host, indirectly benefiting competitors sharing the same individual host? Host monitoring of symbiont performance and the imposition of sanctions on 'cheats' could stabilize mutualism. Here we show that soybeans penalize rhizobia that fail to fix N_2 inside their root nodules. (Tiers, Rousseau, West, & Denison, 2003)

This passage is illustrative of the three central tenets of CMT mentioned in the introduction:

- Metaphors are matters of thought, not merely of language
- We employ inference patterns from one conceptual domain of thought to reason about another domain.

– The systematic correspondences we establish across domains are metaphorical mappings, which are shaped and constrained by our bodily and social experiences in the world.

The examples that follow provide further support these tenets of CMT in diverse biological systems.

Virulence

From an evolutionary perspective, quorum sensing ensures that certain essential functions are executed when and only when the colony has reached an appropriate number. This process enables the very small and vulnerable bacterial cells to amass sufficient capacity and protection. By acting in concert under the influence of quorum sensing the bacterial colony takes on capacities of a larger, more complex entity. A striking example of this is *virulence*.

It is common to use the conceptual metaphor OVERCOMING ILLNESS IS WARFARE in talking about illnesses, ranging from head colds to cancer or Alzheimer's. Thus, a sick person is "battling a bad cold" or "fighting a losing battle against lung cancer". In the same way, harmful microscopic organisms, such as a flu virus or streptococcus bacterial infection are conceptualized as enemies that invade the body, to be killed with agents such as antiviral agents or antibiotics. The invasive agents may be understood metaphorically as employing warfare tactics, such as camouflage, mounting protective armor, or evading contact with the drug.

The term virulence in relation to bacteria denotes a dangerous, potentially deadly agent capable of spreading quickly. When a particular bacterium invades a human body, it may initially lack the numbers to cause significant damage to the host. However by multiplying in the usual way without releasing any damaging virulence factors, a substantial bacterial colony eventually forms. At an appropriate stage of colony growth, as determined by a quorum sensing mechanism, the hitherto inoffensive bacteria simultaneously release one or more virulence factors, so-called effector proteins, through a special secretion system. These proteins are sufficiently abundant to overwhelm the host's defenses, by binding to host antibodies or through some other mechanism. The invading bacterium is thus able to multiply rapidly, and the characteristic symptoms of a proliferating infection set in. For example, the bacterium *Staphylococcus aureus* is a member of the human microbiota, found in approximately 30 percent of the human population. Although this widespread distribution suggests that it is innocuous in humans, *S. aureus* is a very dangerous opportunistic pathogen, one that has become associated with antibiotic resistance. But it becomes virulent only under certain conditions, utilizing one or more quorum sensing systems that eventually activate a set of virulence genes (Antunes, Ferriera, Buckner, & Finlay, 2010).

Scientists studying virulence in a wide range of bacterial systems have learned that it involves many related processes (National Academies Press, 2012). In some cases, invading bacteria produce a fractional mutant version that lacks a typical full virulence. The mutant cells do not pay the full metabolic costs of generating the virulence factor, yet they nevertheless share in the benefits of the virulence factors released by the other bacteria. Here again, in explaining such systems, scientists have labeled the mutant forms metaphorically, as “cheaters”; they benefit from the “public good” provided by the “cooperators” without paying their way. Other variants of this kind of explanatory language have been observed. They illustrate the ways in which the behaviors of microscopic systems are metaphorically conceptualized in terms of social roles drawn from the familiar everyday world. Matters are frequently made more complex by the fact that the cellular medium is populated with many different species of bacteria and other active molecular species. Survival depends on being able to communicate in different ways with cooperating and non-cooperating others, and behave accordingly. Scientists employ a variety of social metaphors in building explanatory models that reflect these complex bacterial colonies.

Biofilms

Anyone who has visited a dental office to have their teeth cleaned has experienced the consequences of biofilm formation. A major task of the dental hygienist is to remove accumulated dental plaque. This hard, complex polymeric material on teeth is a protective mantle for many layers of bacteria. The bacteria opportunistically take advantage of the nutrients available in the mouth, but are typically not pathogenic strains. The first colonizers in forming a dental plaque exploit substances in saliva that allow them to adhere to the tooth surface. These early colonizers emit substances enabling other bacteria to adhere to the first layers. At some point, a quorum sensing process comes into play. When a sufficient collection of cells is present, as detected through inter-cell communication, some or all of the bacterial cells simultaneously release a variety of chemicals that combine with other substances from the immediate environment to form a polymeric matrix that covers all the cells and acts as a shield. The matrix begins to harden after about 48 hours. After several days, it has become tartar, a hard material that is difficult to remove. While the bacteria living in the plaque don’t generally produce toxic substances, they lead to acid formation through their consumption of fermentable sugars in the mouth, thus contributing to tooth decay. Plaque can also contribute to gum disease.

Dental plaque is but one of many examples of biofilms, complex aggregations usually made up of multiple bacterial species. They thrive on nearly every surface, from kitchen sinks to doorknobs to the linings of our stomachs and the surfaces of hip replacements. Depending on their location, the biofilms protect the bacteria from ultraviolet radiation, dehydration, cleansing agents and toxins such as antibiotics. Biofilms can contain many species of infectious strains of bacteria that are serious problems in medical settings - for example on the surfaces of implanted medical devices, or in the respiratory system. Biofilms are organized in much the manner of a human community, with individual species (metaphorically) taking on particular tasks. The environment surrounding each cell therefore contains a great variety of signaling (autoinducer) molecules. Some are specific to an individual species, others are involved in interspecies signaling. The following passage, like many others in the scientific literature, reveals the extent to which scientists conceptualize processes in the bacterial world in terms of experiential gestalts of considerable complexity drawn from the social world:

> Every quorum-sensing bacterium has multiple quorum-sensing circuits. That is, bacteria are multilingual, and they converse using a rich chemical lexicon. Beyond simply counting, bacteria use different quorum-sensing molecules to distinguish between self and non-self, and they decode blends of autoinducer molecules to extract information about the ratio of different species present.[B]acteria employ a chemical vocabulary composed of molecules that identify self, non-self but closely related, and non-related. In essence they can determine "you are my sibling", or "you are my cousin", or "you are not family." (Bassler, 2012)

Notice in these descriptions of bacterial systems two important threads drawn from our prior discussions: (a) There are multiple examples of the semiotic metaphor; communication is ubiquitous; (b) New properties emerge from the behaviors of the simplest assemblies of bacteria as they communicate, form new structures, and through interactions with other species generate still higher levels of organization with new properties. Emergence / supervenience is a powerful metaphor that organizes the scientist's understanding of a complex system in terms of simpler constituents.

The social conceptual frames I have described, and many others like them, are not the detailed content of the scientist's understanding of the biology involved, but rather provide a general framework for understanding and generating hypotheses. The goals of research in this area are to understand bacterial behaviors in terms of molecular components and microscopic level constructions. Thus, for example, scientists strive to know the molecular structures of the autoinducer molecules, and to understand how variations in their structures arise and govern cellular responses. One might therefore think of the social metaphors as overarching representations of how the molecular-level processes are governed and relate to one another. They provide essential high level interpretive views of what may be going on in the system, as it seems to the scientist. Most importantly, the metaphorical representations inspire and guide searches for the cellular and molecular actors.

We can see in the examples presented how the three meta-metaphors alluded to earlier (the semiotic metaphor, teleology, and emergence/supervenience) encompass the gamut of metaphors in biology. The semiotic metaphor is obviously the overarching concept in quorum sensing. It is at work also in helping the scientist understand interspecies communication. Teleological language is commonplace throughout the examples I have cited. Emergence is seen in the idea that collectives of simpler entities – from flocks of birds and beehives to bacterial colonies – possess emergent properties not possessed by individuals. Supervenience is evident in the ways in which the behaviors of individuals in collectives are constrained in highly structured ways. The systematicity of the metaphors encountered, their evident origins in experiential gestalts from the social lives of scientists, and their efficacy in generating productive new directions for research, are all accounted for by CMT, and provide strong support for the theory.

The explanatory language used in biology is consistent with the idea that a conceptual understanding of the natural world is the product of both embodied and social experience. However "right" any explanation may seem once established, no single metaphor or collection of them can be an objective representation of "truth" in science. The success of CMT in accounting for scientific explanation enlightens us about our human capacities for understanding the natural world. But we see also that our capacities are limited by the conceptual frameworks possible given our embodied experiences in the physical world together with experiential gestalts derived from our personal and cultural lives.

Conceptual metaphors, abduction and science education

Science educators are perennially concerned with the most effective methods for imparting information about the natural world. Much of the discussion has to do with specifics of what *content* should be taught in any particular discipline. Too often, however science educators fail to address questions of how scientists acquire new knowledge, and the means by which new scientific findings are disseminated, evaluated and eventually accepted or rejected by other scientists. The roles of metaphorical thought are often neglected altogether, as are the processes by which judgments are made regarding new hypotheses and models. Students are left without a sense of how to judge the reliability of scientific claims.

There is no general agreement on a single best way to study the natural world. The objects of study vary greatly and the tools available are variable and subject to continual change. Philosophers of science have attempted to define rules and criteria that can best ensure that the conclusions reached through processes of data-gathering, analysis and reasoning lead to the best possible account of nature, an account that comes as close as possible to "true". Although he is seldom given credit for it, Charles S. Peirce (1857–1914), an American scientist and philosopher, proposed an internally self-consistent approach sometimes referred to as the Pragmatic Theory of Truth. Peirce was a remarkable, brilliant and strange person. Over his lifetime he made important contributions to logic (his major interest), chemistry and other physical sciences, economics, and a broad range of topics in the social sciences. He is considered the father of Pragmatism, a distinctly American contribution to philosophy. However, Peirce was eccentric and difficult, with the result that he was underappreciated during his lifetime. A great deal of his voluminous writing was lost or is only now being discovered (Burch, 2014).

A coherent explanation of any observation of the natural world can result only from a process of inferential reasoning. The three widely recognized forms of inference are deductive, inductive and abductive. Because Peirce was passionately interested in logic, he began by considering how these three recognized forms of argument might be coherently related in an integrated methodology. In deductive reasoning, a conclusion formed from a set of premises is *necessarily* true if the premises on which it is based are true. For example: All kangaroos are marsupials. X is a kangaroo. Therefore X is a marsupial. Ordinarily when searching for explanations, it is rarely the case that the working premises can be assumed to be necessarily true. Inferences made are therefore most usually non-necessary.

The two commonly recognized forms of non-necessary inference are induction and abduction. Peirce is generally credited with recognizing abduction as an important form of reasoning (Douven, 2011). *Inductive* inferences commonly depend on statistical data, such as the observed frequencies of occurrence of a particular feature in a given population. For example, all morbidly obese mice in a given laboratory population being studied are found to host a particular gut microbiome Y. Mouse X is morbidly obese. Therefore, mouse X hosts gut microbiome Y. The inference might not be completely logical – that is, not admitting of any other conclusion. Nonetheless, under the conditions of the experiment it is highly likely to be true. In inductive inference, the basis is normally statistical. If all the swans you or anyone you know have ever observed are white, it is reasonable to infer that all swans are white.

Abductive inference, while similar to inductive inference, differs in its underlying rationale. The emphasis is on what provides *the best explanation for the observations*. In Peirce's framework, the scientific method begins with the formation of some sort of conjecture, or hypothesis, that might account for a phenomenon or set of data. The reasoning goes that if the hypothesis is true, then the phenomenon or set of data are what we would expect to find. According to Peirce, if the abductive hypothesis passes muster, the next stage in the investigation is to employ deductive reasoning, to deduce other observable phenomena or data that should follow logically. If the second stage is successful, further and more detailed hypotheses are advanced and tested. If not, the hypotheses are modified in light of new evidence, and a loop of inferences and testing ensues. Peirce argued that the overall procedure is a form of inductive inference, in which we take the ability of the hypotheses to explain the accumulated evidence as a measure of their correctness. The process is commonly referred to as *Inference to the Best Explanation* (Lipton, 2000). Conceptual metaphors are at the heart of this, because the hypotheses or conjectures advanced are based on embodied conceptual understanding of the natural world, or concepts grounded in experiential gestalts.

Hastings and Nealson's explanation for how *A.fischeri* bacteria come to the point of luminescing in the mantle of the Hawaiian bobtail shrimp provides an illustration. Based on their observations, they formulated the hypothesis that there is a particular small molecule present in the solution containing the bacteria. When its concentration reaches a certain level, the bacteria simultaneously express genes that result in luminescence from every cell. This hypothesis, named quorum sensing, is explanatory and predictive. The abductive inference in this case is just this: If the hypothesis is true, we should be able to find the small molecule, the autoinducer, that evokes the collective response of the bacteria. The abductive inference sends the scientist in search of the elusive autoinducer, of which, up to that point, no one had an inkling. If the predictions of the quorum sensing hypothesis are found to reliably match observations, the truth value of the model is increased. Further questions and predictions arise as guided observations accumulate.

Educating students about science often consists in imposing upon them memorization of a great many facts, names and processes. Important as this may be in producing "literacy" in a particular science, the more important thing to teach students about science in general is how scientists come to possess reliable knowledge. There is no single pathway to such knowledge. Peirce's scientific method is the single most effective and commonly applied approach. The abductive inference at its heart is based on the inference structure inherent in a conceptual metaphor, grounded in the scientist's embodied and social understandings. By using conceptual metaphors the scientist arrives at contingent, testable models and theories that describe the world. They do not aim toward the unattainable goal of "absolute" truth, but toward reliability and accuracy. The world is filled with ample evidence that the scientific method when exercised this way works. Humans are able to perform amazing surgical procedures, land a complex device on a relatively tiny comet 300 million miles from Earth, and make progress in understanding the origins and progression of Alzheimer's disease. Conceptual metaphorical thought has been vital in all this progress.

Criticisms and defenses of CMT in science and science education

While CMT has been unquestionably influential in metaphor studies, it has also been criticized on various grounds by some scholars who approach metaphor theory from perspectives grounded in philosophy of language, literary theory, or linguistics (Camp, 2006; Guttenplan, 2005; McClone, 2007; Murphy, 1996). This is not an appropriate place to mount a comprehensive defense of CMT that addresses the many caveats and outright disagreements mounted against it. Gibbs and Lakoff and Johnson have addressed most of them in comprehensive, wide-ranging papers (Gibbs, 2001; Johnson & Lakoff, 2002).

It is important to emphasize that in scientific practice metaphor usage serves particular purposes. The language employed in scientific discourse often has features we associate with ordinary discourse, and we expect conventional metaphors to arise there as they would in other situations. However, conceptual metaphors such as quorum sensing, the cell as a factory, and a host of others, play essential roles in science because they are at the core of scientific explanation. Whatever may be the merits of critiques addressing how CMT can be applied more generally, the case for its efficacy in the practice of science is very strong. Here are additional considerations that should be kept in mind in evaluating CMT in this domain:

- Metaphoric usage is ubiquitous in scientific speech and writing that relates to scientific observation, creation of hypotheses and theory development. Indeed, it is difficult to find instances where metaphor is not a key element in scientific thought and communication. The patterns of metaphor usage are highly consistent with the tenets of CMT, as I have pointed out elsewhere (Brown, 2003) and illustrated further in this paper.
- It is frequently charged that the "conventional" metaphors that form the basis of our everyday thoughts and conversations are not products of our ongoing thought processes, but only linguistic conventions, metaphors that have lost their connections with the conceptual mappings that brought them into existence. Whatever the merits of such claims as regards everyday language use, and they have been rebutted (Gibbs, 2001), metaphors employed as explanations of new observations in science are nearly always novel. Furthermore, even in cases where a scientific metaphor has been in use for a long time, its conceptual import remains. For example, the metaphor of a "chaperone

protein" as one that acts to protect another protein from alteration, was freshly coined in 1978 (Brown, 2003, pp. 150–155). The metaphor proved to be highly productive, and applications of the concept spread rapidly. Today a Google search of the term "chaperone protein" returns in excess of 4 million entries. (There is, of course, considerable redundancy in this number, but it is evident that the concept of 'chaperone protein' remains actively employed long after its initial formulation.) It cannot be said that the term has become a dead metaphor, for several reasons. Most importantly, the meaning of "chaperone protein" is subject to continual revision as new findings and examples arise, and the term is applied to newly discovered systems.

– CMT accounts brilliantly for the fact that metaphors employed by scientists in accounting for scientific observations and in hypothesis formation draw upon conventional metaphors born of both the scientist's physical experiences of living in the world, and those deriving from experiential gestalts based upon social experiences and understandings. The systematicity and structural cohesiveness of metaphorical usages in science are consistent with the idea that fundamental conceptual processes are at work. For example, the metaphor of quorum sensing has been applied in a consistent manner to a host of highly varied situations in bacteriology. A well-formulated scientific metaphor is not merely a catachrestic label; it can do real work. When there exist viable cross-domain mappings, it is capable of stimulating new hypotheses and suggesting new experiments. No theory of metaphor other than CMT accounts satisfactorily for the breadth, consistency and productive roles of metaphor usage in science.

Finally, I close with a few comments on areas that appear to be ripe for further study of metaphor as it applies to science education. For some, a focus on conceptual metaphor entirely from the perspective of language and thought omits important aspects of metaphor's roles. To quote Gerard Steen:

> Metaphors are not only a matter of thought (with conceptual structures bridging conceptual domains or mental spaces) and a matter of language (with linguistic expressions in context indicating at least one aspect of such cross-domain mappings in thought), but also of communication, with linguistic expressions in context suggesting whether the metaphor has a specific value to the interlocutors as a distinct communicative (typically rhetorical) device – or not
>
> (Steen, 2015, p. 78)

All three of these dimensions of metaphor (thought, language, communication) are involved in scientific activity broadly. The focus in this paper has been largely on the roles of metaphor in the practice of science: That is, on the thought processes involved in making sense of scientifically motivated observations of things and events in the world. The evidence I have pointed to further establishes the primary role of conceptual metaphors, grounded in embodied experiences and social experiences of ordinary life, in scientific thought. Those same conceptual frameworks operate in forming the language scientists use in communicating with one another via speech or writing, and, of equal importance, in communicating to broader audiences about scientific results. However, as Steen rightly points out, the distinct dimensions, which can be roughly categorized as thought, language and communication, may produce differing patterns of thought in discourse. I offer a few comments here on the idea of *deliberate metaphor*, introduced by Steen (Steen, 2008, 2014) as it might apply to science education.

Deliberate metaphor use is the purposeful use of a metaphor as a metaphor. It often occurs in science teaching that a particular metaphor is called for to get across some insight or point of information. For example, I might say, "Imagine that a water molecule consists of a rubbery sphere connected symmetrically to two smaller rubbery spheres of equal size by rather stiff springs." This is a deliberate metaphor, in that the listener is specifically invited to set up a cross-domain mapping between a microscopic entity, a water molecule, for which we have various kinds of experimental evidence, and the physical model described in the metaphor. I might have chosen a different metaphorical model for the water molecule, for example, "Imagine that a water molecule consists of one tiny mass with a positive electrical charge of eight, and two positively charged tiny centers each with a charge of one, buried in a cloud of ten very low mass negative particles in extremely fast motion." The second deliberate metaphor demands more background knowledge on the part of the listener than the first one, but in a particular teaching situation it could be the better one to use.

It is frequently the case that the teacher needs to make a choice of one metaphor over another based on fairly complex considerations, such as the student's state of understanding of the domain under discussion, consistency with other metaphors that may have already been employed, and the particular aspect of the system demanding explanation. It is not surprising, then, that many metaphors used in science are "deliberate", and tailored to answer to particular pedagogical aims of the teacher. Consider this example drawn from a paper by Bruce Alberts dealing with the education of molecular biologists:

> …the entire cell can be viewed as a factory that contains an elaborate network of interlocking assembly lines, each of which is composed of a set of large protein machines. (Alberts, 1998)

In this example, the metaphor to which Alberts specifically calls attention is that of the cell as a factory. The short quote also contains several metaphors not specifically identified as such, including "interlocking assembly lines" and "large protein machines", that are simply entailments of the more general factory metaphor. The deliberate metaphor employed by Alberts is that of the cell as a factory. He suggests that proteins are somehow able to do machine-like work, perhaps cranking out new parts, and that this work is done in a systematic way in an organized array analogous to an assembly line.

The choice of calling attention to a metaphor, thus creating a meta-metaphorical entity, is often made to distinguish one key metaphorical model from another that might be employed in discussing the same target domain. For example, Alberts might have alternatively characterized the cell as a city, into which new substances enter and other substances pass out, in which certain proteins exercise surveillance over others, and destroy defective ones, in which strict traffic rules apply. In this frequently used metaphor for the cell, certain proteins are said to practice "triage." But Alberts chose the metaphor of the factory because he wanted to focus on proteins as machines; much of the rest of his paper is concerned with developing that notion.

While there are plenty of deliberate metaphors in science and in science pedagogy, the concepts employed in accounting for an observation or forming part of a hypothesis are typically grounded in basic conceptual understandings. Thus, we find language such as "the electron is promoted to a higher level", "the energy has a sharp minimum at 2.2 Angstroms", the term "fitness landscape" in which height represents degree of fitness, and so on. Such conventional conceptual metaphors abound in scientific discourse. Deliberate metaphors have their place as a considered choice of one metaphor over another for pedagogical reasons or possibly as a persuasive move. Deliberate metaphors are typically instantiations of a more general primary embodied metaphor or deeply grounded social metaphor. For example, Steen uses the following extract from a magazine article as an example of a deliberate metaphor: "Imagine your brain as a house filled with lights" (Steen, 2015). This metaphor makes sense only in terms of a more basic metaphor of the form: UNDERSTANDING IS SEEING. The metaphors of the cell as a factory or hospital rest on a metaphor such as LIFE IS PROCESS. Gibbs has challenged the very notion of deliberate metaphor, partly on the grounds that calling out a metaphor as such does nothing to change its relationship to the underlying primary metaphor (Gibbs, 2015, pp. 77–87). However, as I noted above, the deliberate metaphor does direct attention to one of what might be many metaphors for the target domain. For example, the brain might be imagined as a computer, a filing cabinet, consumer of energy, and so on. Deliberately calling attention to the brain as a house filled with lights may assist the listener to direct thought away from other metaphors for the brain that would be inappropriate for the application at hand. It is in this sense that deliberate metaphor as a pedagogical device has potential value.

Summary

My aim in this chapter has been to apply Conceptual Metaphor Theory (CMT) to the domain of cellular and molecular biology, in which conceptual metaphors drawn from the social domain are widely employed in reasoning about observations, forming hypotheses and generating thoughts for new experiments. Following an introduction of the central ideas of CMT, three overarching metaphors of special importance have been discussed: the Semiotic Metaphor, Teleology and Emergence and Supervenience. The centrality of these three primary conceptual metaphors to biology is demonstrated by showing their roles in discussions and theories related to evolution, a theory that underlies all of modern biology.

The study of living systems, even at the microscopic level, challenges the scientist to think in terms of metaphorical constructs that are sufficiently complex to capture a wide range of collective behaviors. In addition to drawing upon embodied experiences in the physical world, the scientist may call upon social experiences, including experiential gestalts of some complexity, in formulating hypotheses and models. The study of cellular systems that are focused on here calls upon metaphors from three source domains: structure, processes and – most importantly - communication.

Bacteria are ubiquitous unicellular organisms found throughout all living systems. These microscopic entities are too simple to exhibit complex behavior on a single-cell basis. However, intercellular communication leads to a wide range of collective behaviors, as illustrated and explained in this chapter with numerous examples. The explanatory metaphors employed to account for bacterial behaviors, formulate hypotheses and make predictions about the behaviors of the systems, are sophisticated. They call upon familiar social experiential gestalts suggested by terms such as "quorum sensing", "cooperation", "kin recognition", and "cheating". As demonstrated in this chapter, the range and systematicity of conceptual social metaphors in the language scientists employ attests to their fundamental importance in the biological sciences.

An understanding of conceptual metaphor and the roles it plays in science should be a prominent goal in all areas of science education. The most important mode of scientific reasoning, abduction, identified primarily by Charles S. Peirce, involves as a first step establishing a hypothesis, based primarily on conceptual metaphorical reasoning. Abductive reasoning consists in postulating that if a particular hypothesis regarding a system under study is true, one or more properties of the system follow. The scientist is then led to new experiments to test whether a particular predicted property is observed. If it is, the hypothesis is strengthened. If not, the hypothesis is amended or rejected. Successful accumulation of hypotheses leads to metaphorical models grounded in conceptual metaphors, a key ingredient in developing a “best explanation.” Students are not generally familiar with the notion of metaphorical thought, unaware that conventional metaphors form the basis of their everyday thought processes. Because conceptual metaphors are so central to scientific reasoning and explanation, their explicit identification – that is, use of deliberate metaphor – can help to inculcate a deeper sense of the importance of conceptual metaphors.

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CHAPTER 3

Coordinating metaphors in science, learning and instruction

The case of energy

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A substantial body of research has accumulated on the use of metaphor and analogy in science, their role in the construction of novel concepts during learning, and their strategic deployment in instruction. Despite this significant body of work, we still do not have a coherent picture of the role of metaphor in how a specific scientific concept comes to be understood. This chapter draws on the theories of conceptual metaphor and blending to put forward a perspective on how metaphor makes a scientific concept accessible; crucially, the account coordinates analyses of the roles of metaphor in science, learning and instruction. The chapter offers a case study of the concept of energy to illustrate the perspective.

Keywords: conceptual metaphor, blending, science, learning, instruction, energy

Introduction

There is a large and important body of work that has taught us a lot about the role of metaphor in science, learning and instruction. We have learned that creative leaps that have been very important in the history of science have often involved metaphor or analogy (e.g. Gentner & Jeziorski, 1993; Nersessian, 2008). We have learned a lot about the kinds of cognitive mechanisms involved when knowledge in an unfamiliar domain is built based on knowledge in another more familiar domain (e.g. Gentner, 1983; Glucksberg & Keysar, 1993). The same mechanisms have been shown to be at work in the minds of scientists as they come up with novel explanations of phenomena and the minds of learners making sense of scientific ideas that they encounter for the first time (Clement, 2009; Gentner, 1989; Gentner & Gentner, 1983).

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We have also learned a lot about *what* metaphors and analogies are effective in teaching difficult scientific ideas and *how* these metaphors and analogies should be introduced in classroom instruction (Aubusson, Harrison, & Ritchie, 2006). For example, we have learned that a single metaphor or analogy is often insufficient (and sometimes harmful) and that multiple metaphors or analogies carefully coordinated are sometimes needed to clarify different aspects of a challenging and complex idea (e.g. Spiro, Feltovitch, Coulson, & Anderson, 1989). This literature has been thoroughly reviewed (Bailer-Jones, 2002; Duit, 1991; Gentner & Wolff, 2000) and edited volumes have compiled these contributions comprehensively (Gibbs, 2008; Hallyn, 2000; Ortony, 1993; Vosniadou & Ortony, 1989).

In this chapter, I aim to offer a different perspective on metaphor and analogy in science, learning and instruction that incorporates three elements: (1) a focus on metaphor as a patterned discursive phenomenon in the language of scientists, textbooks and learners; (2) the embodiment assumption that an understanding of a scientific concept (even by scientists themselves) is grounded metaphorically in knowledge derived from sensorimotor experience and involves the coordination of multiple metaphorical mappings; and (3) the claim that to understand how a particular scientific concept comes to be understood we need coordinated analyses that examine the use of metaphors in science, by learners and in the context of formal instruction in classrooms. That is, I use the word "coordinate" in this chapter in two senses: to understand the role of metaphor in learning science our *analyses* in different contexts – in science, in learning, and in instruction – must be *coordinated*; moreover, we will find that one of the features of scientific expertise is the ability to *coordinate* – that is, use together strategically – a variety of different metaphors in a variety of contexts. Research is increasingly providing accounts of the patterned use of metaphor in the language of science, recognizing the embodied basis of scientific understanding and the implications of these phenomena for formal instruction have been addressed (see contributions in Amin, Jeppsson, & Haglund, 2015). However, no single account has brought together research on metaphor and analogy in the contexts of science, learning and instruction in a specific scientific domain.

A critical mass of research on the use of metaphor to conceptualize the concept of energy (and related concepts such as heat and entropy) has now emerged. Individual studies of my own and studies of others have examined implicit metaphors used by scientists and in the everyday (pre-instruction) language of the learner, described the implicit and explicit metaphors and analogies used by textbook writers and teachers, and discussed the role of metaphorical mapping in learning this abstract concept. In this chapter, I will bring together these individual studies to discuss how scientists ground their understanding of energy metaphorically in multiple image schematic knowledge structures (i.e. abstractions from sensorimotor experiences) and how this is reflected in the language of scientists and communicated in textbooks. I will also discuss some of the obstacles learners face in appropriating metaphors implicit in scientific discourse dealing with energy. Finally, I discuss the implications of these phenomena for formal instruction. Along the way, I will point out where there is a need for further research to fill gaps in our understanding.

The scientific concept of energy

Central to the concept of energy is the notion that there is a quantity that remains unchanged across the many changes that occur in the physical world. Objects interact with each other resulting in changes of speed and the rises and falls in temperature of the objects concerned; gases can be expanded and compressed, resulting in changes in the volume, pressure and temperature of the gas, the container and its surroundings; chemical reactions can occur involving the breaking and forming of bonds between atoms and changes in the temperature of reactants and products; and chemical reactions and physical transformations can occur within biological systems to support the vital processes of life. And, across all such changes, the quantity we refer to as *energy* remains unchanged; this is the principle of *conservation of energy*.

To keep track of this conserved quantity across this variety of changes, scientists follow *energy exchanges* between components of a system such as colliding objects and the interaction of gases with their containers and its surroundings. Heat, the transfer of the (kinetic) energy of motion from hot to cold objects is an example of energy exchange. Scientists also track the different *forms* in which energy can be manifested such as the motion of objects, compressed springs, and chemical bonds. Finally, they distinguish between forms of energy in their capacity "to do work," contrasting say a falling weight that lifts another (a useful form of energy) to the diffuse motion of millions of randomly colliding particles (not very useful). The latter kind of energy is said to be *degraded* in contrast to the former. Entropy is a quantity that captures the tendency of natural processes to occur such that energy is increasingly degraded. So not only is energy conserved (the first law of thermodynamics), spontaneous processes are governed by the principle that entropy will increase, energy transformations will occur such that energy is increasingly degraded (the second law of thermodynamics). Thus, the scientific concept of energy has four basic aspects: it can be exchanged, it can be manifested in a variety of forms, it is conserved across physical changes, and it has a spontaneous tendency to be degraded. Moreover, energy is not "a thing" but is an abstract, mathematical quantity.

Perspectives on metaphor: Conceptual metaphor and blending

Given the abstract mathematical nature of the concept of energy, it is not surprising that metaphor has often been recruited to make sense of all four of its basic aspects. For example, the phrase "energy *exchange*" is often used without awareness of its metaphorical nature. Most literally, the energy of some component of a system is a *state* captured by scientists as a mathematical quantity. When two components interact, there can be a reduction of the energy state of one component and an increase in the other. Nothing is literally *exchanged*; no *thing* passes from one component to another. But the word "exchange" does quickly convey the idea of the reduction of a state of energy of one component concomitant with, and causally related to, the increase (by the same amount) of the state of energy of the other. The simple schematic image of the *transfer of a substance from one location to another* concisely and concretely conveys the various aspects of the idea: reduction of energy state of component 1 (conveyed by the idea of *loss* of a substance/possession), increase of energy state of component 2 (conveyed by the idea of *gain* of a substance/possession), the reduction in 1 is equal to the increase in 2 (conveyed by the idea that with transfer of a substance/possession what is lost *is* what is gained), and interaction between the two is the cause of this mutual change (conveyed by the notion of transfer, which inherently links the gain to the loss of substance and requires some kind of spatial/temporal contiguity).

A similar metaphorical unpacking can be offered for many apparently non-metaphorical expressions that are in common use in talking and writing about energy: 'we find energy *in* various forms,' 'energy is transformed *from* potential *to* kinetic energy,' 'the energy *absorbed ejects* an electron,' 'the energy is *lost* as heat,' and 'the increase in entropy *drives* the process." This kind of implicit use of metaphor is found in the language of science, in the language of the layperson talking about energy and heat as everyday notions, and in the textbooks, lectures and classroom discourse to which learners are exposed. The question I address in this chapter is how to analyze this use of metaphor both within and across different contexts of language use to see the order and pattern in what might seem to be a haphazard phenomenon. Moreover, I try to draw out the pedagogical implications of this patterned, yet complex, discursive phenomenon.

Two related theoretical perspectives from the field of cognitive linguistics – Conceptual Metaphor and Blending – have provided researchers interested in metaphor in science, learning and instruction with useful analytical tools to discern some order in this apparent discursive chaos. In this section, I introduce each of these two theoretical perspectives briefly. I then turn to a discussion of how researchers have used them to study the metaphorical construal of energy (and the related concepts of heat and entropy) in science, learning and instruction.

Conceptual metaphor theory: Identifying conceptual patterns underlying language use

The framework of conceptual metaphor was developed by Lakoff and Johnson in their seminal books *Metaphors We Live By* (1980) and *Philosophy in the Flesh* (1999). In these books, they pointed out that many expressions in everyday language which are assumed to be literal are, on closer scrutiny, actually instances of metaphorical language use. Moreover, they argued that what might seem to be random instances of fossilized metaphorical expressions are in fact manifestations of underlying systematic mappings between conceptual domains. For example, 'I have a cold'/ 'I have patience,' 'I caught a cold'/'I'm losing patience' and 'He gave me a cold'/'Her presence gave me patience' can be seen as reflecting a set of related metaphorical mappings between conceptual domains; namely, STATES ARE POSSESSIONS, CHANGE OF STATE IS MOVEMENT OF A POSSESSION, and CAUSED CHANGE OF STATE IS FORCED MOVEMENT OF A POSSESSION, respectively.

These three mappings can be seen as sub-mappings of a more general conceptual metaphor that Lakoff and Johnson called the Object Event Structure metaphor. The source domains in these mappings include notions like *possession*, *movement*, *force* etc. A key claim of the theory of conceptual metaphor is that many of the source domains of conceptual metaphors derive from our early sensorimotor experiences of moving about, manipulating materials, giving and receiving objects, putting things in and taking them out of containers, etc. Abstractions from these experiences give rise to knowledge structures – referred to as image-schemas – that are analogical representations of those experiences (Johnson, 1987). Because many abstract concepts are conceptualized metaphorically in terms of image-schemas, our understanding of these abstract concepts is said to be embodied.

In addition to systematicity, the phenomenon of conceptual metaphor underlying language also involves subtle shifts of perspective. For example, 'I'm in love,' 'I fell into a depression' and 'He pulled me out of this grim mood' reflect the conceptual mappings STATES ARE LOCATIONS, CHANGE OF STATE IS MOVEMENT, and CAUSED CHANGE OF STATE IS FORCED MOVEMENT, all sub-mappings of the Location Event Structure metaphor. The two conceptual metaphor systems – object and location event structure metaphors – involve subtle figure-ground reversals: in the first, states are things which can move from one location to another, with locations representing the entity the state of which we are concerned with; in the second, it is the state that is construed as the location and it is the entity that is changing state that is construed as moving. These are just two of the very many metaphorical patterns identified by Lakoff and Johnson and other researchers; a vast literature now documents very many metaphorical mappings, sets of mappings, perspectival shifts and a wide range of metaphorical phenomena (Kövecses, 2010).

Blending theory: Conceptual dynamics in the flow of discourse

In parallel, a framework referred to as Blending (or Conceptual Integration) Theory was developed by Fauconnier and Turner (Fauconnier, 1996; Fauconnier & Turner, 2002). Blending theory has also been concerned with mappings between conceptual domains underlying language use. Two key features of blending theory are worth noting that distinguish it from the theory of conceptual metaphor.

First, blending theory describes mappings between more than two domains and does not assume that mappings are always unidirectional from a source to a target domain. Instead, elements of language (and other symbol systems) are seen to invite language users to invoke a number of conceptual frames, identify correspondences between these frames and often map elements of both into a blend. Consider, as an illustration, an example discussed in Turner and Fauconnier (1995). In 1993, a catamaran sailed from San Francisco to Boston in an effort to break the record of a clipper that sailed the same route in 1853. At some point while the catamaran was still at sea, a newspaper reported that "the catamaran was 'barely maintaining a 4.5 day lead' over the clipper."

As Turner and Fauconnier explain, this sentence cannot be understood without invoking two distinct conceptual frames (they use the construct of a conceptual "space"): one in which the catamaran is conceptualized as sailing in 1993; and another in which the clipper is sailing in 1853. To make sense of the sentence a third frame (space) is needed into which the two boats and the route are projected, the dates in the two cases are not projected and the idea of a race is invoked so that the notion of competition and 'breaking a record' can be made sense of. Fauconnier, Turner and many others have now documented many ways in which linguistic elements (and the elements of other symbolic systems) invite language users to invoke mental spaces and selectively project these onto a blended space for the purposes of communication and reasoning (Fauconnier & Turner, 2002).

A second key contrast with conceptual metaphor theory is that blending theory has also been concerned with mappings that are novel and emerge on the fly during the course of discursive interaction. Conceptual metaphors are stable, often very conventional mappings, reflected in conventional language use. Blends can be stable and reflect patterns of projection that are highly conventionalized (consider for example conventional counterfactual constructions such as "If I were you I would …"). However, blends will often be constructed for the first time in a given discursive moment and so interpreting this on the part of the listener will require creative, interpretive leaps performed quickly during an exchange.

The metaphorical construal of energy in scientific discourse

These two perspectives have been used to examine the use of metaphor to construe the concept of energy in scientific discourse. In this section, I synthesize this body of work. I use the term "discourse" to encompass the use of a variety of representational forms such as language, diagrams, gestures, and equations (often used together) to achieve some purpose (Gee, 1996). The set of analyses discussed here provide a picture of a discursive complexity within which order can be discerned when conceptual metaphor and blending perspectives are adopted as lenses of interpretation. The analyses are organized in terms of the four aspects of the concept of energy outlined above: transfer, transformation, conservation and degradation. Considering energy transfer and degradation means that we must also look at the concepts of heat and entropy, respectively.

Metaphorical construal of energy: Transfer, transformation and conservation

In Amin (2009), I reported an analysis of the metaphorical use of the term *energy* in *Feynman's Lectures on Physics* (Feynman, Leighton, R., & Sands, 1963). Feynman's metaphorical construal of energy was found to be extensive. Consider the following sentences from Feynman's text:

> It [the atom] either *gains* or *loses* energy, depending upon whether the piston is moving one way or another when the atom strikes (I–39–7)

> …the elastic energy … is converted to kinetic energy and it *goes back* and *forth between* compressing and stretching the spring and the kinetic energy of motion (I–4–6)

> …the energy *goes up* very rapidly because they repel each other (I–14–7)

> It is not always easy to *separate* the total kinetic energy of a thing *into two parts*, kinetic energy and potential energy. (I–14–6)

To identify what systematicity exists in Feynman's extensive use of metaphor, I conducted an analysis of a large corpus of sentences in which the term energy appears, organizing all metaphorical construals of energy in terms of the first three aspects of the concept of energy: exchange or transport, transformation and conservation (metaphorical construal of energy degradation is not readily seen simply by analyzing the use of the term *energy*; see discussion of entropy and the second law of thermodynamics below). A conceptual metaphor perspective was used to group metaphorical expressions into categories where each category reflects a mapping between the same source and target domains.

To construe energy *exchange* between different components of a system, Feynman systematically employs sets of mappings that are sub-mappings of the object event structure metaphor (OES) (Lakoff & Johnson, 1999) and elaborations of it. The sub-mappings identified are listed below, with phrase fragments used in brackets to illustrate (for more complete illustrations see Table 2 in Amin, 2009):

1. ENERGETIC STATE IS A POSSESSION ('the energy an object *has*')
2. CHANGE IN ENERGETIC STATE IS MOVEMENT OF A POSSESSION ('it *gains* or *loses* energy')
3. CAUSED CHANGE IN ENERGETIC STATE IS TRANSFER OF A POSSESSION ('how much energy will they have *given to* the material')

The above mappings amount to the application of the OES system of mappings, also found extensively in everyday language as seen earlier, to scientific discourse dealing with the concept of energy. The construal of energy as "possessed" by some component of a system is further elaborated: energy is understood as the content of a container (see 4 & 5 below); this content can also be further construed as a resource that can be used for some purpose (see 6 & 7 below):

4. ENERGETIC STATE IS CONTENT OF A CONTAINER ('energy *in* an electric field')
5. CHANGE OF ENERGETIC STATE IS MOVEMENT INTO (OR OUT OF) A CONTAINER ('we *put* energy *into* the gas')
6. ENERGY IN SOME FORM IS A RESOURCE ('the energy *stored in* inductance').
7. ACCESSING STORED ENERGY IS REMOVAL OF RESTRAINT ('when we burn gasoline energy is *liberated*')

In contrast, *forms of energy* and *energy transformation* are metaphorically construed in terms of the sub-mappings of the location event structure (LES) metaphor. As mentioned earlier, this involves a figure-ground reversal when compared to the OES metaphor (i.e. where, in the OES metaphor, states are construed as possessions and the entities in some state as possessor or container, in the LES metaphor states are construed as the container). Applications of the LES metaphor are as follows:

8. FORMS OF ENERGY ARE LOCATIONS/CONTAINERS ('existence of energy *in* other forms')
9. CHANGES OF FORM OF ENERGY IS MOVEMENT INTO (OUT OF) CONTAINERS ('*goes back* and *forth bet*ween compressing and stretching the spring and the kinetic energy')

In mappings 8 and 9 above, it is the forms of energy themselves that are construed as containers. This construal of energy forms as containers and transformations as movement in and out of containers allows the scientist to keep track of different manifestations of energy.

The third aspect of energy addressed in this analysis was *conservation*. To account for energy conservation, it is necessary to quantify energy states of various components of a system and keep track of contributions of the energy states of components to the energy of the whole system, which must be conserved. A variety of different metaphorical mappings support this process of quantification and documenting conservation:

10. ENERGY STATE IS AMOUNT OF SUBSTANCE ('the *amount of* energy')
11. INCREASE/DECREASE IN ENERGY STATE IS MOVEMENT OF AN OBJECT/ENERGY ON A LINEAR SCALE ('the energy *goes up*')
12. ENERGY STATES ARE LOCATIONS (on a vertical scale) ('they are *in* the lowest energy state')
13. ENERGY STATE INCREASES/DECREASES (OF A SYSTEM COMPONENT) ARE MOVEMENTS (of the system component) ('a *transition from* energy E3 *to* energy E1')
14. CAUSING ENERGY STATE INCREASES/DECREASES IS FORCED MOVEMENT (ON A VERTICAL SCALE) ('*acceleratin*g electrons *to high* energies')
15. ENERGY OF A SYSTEM COMPONENT IS A PART OF A WHOLE ('*separate* the total energy of thing *into two parts*')

The analysis above identifies fifteen different mappings between an aspect of the concept of energy (target domain) and an image-schematic source domain. The presentation above groups these mappings together in sets, often as sub-mappings of a more general mapping between broader source and target domains; thus, there is systematicity that cuts across this diversity of metaphorical usage. Indeed, the fifteen mappings can be distilled to three distinct metaphorical construal types: energy as a substance (which can be construed as a resource *for* some purpose and in terms of parts of a whole and can be exchanged between system components and transformed from one form to another); energy forms as containers; and energy states as locations on a vertical scale.

This summary statement is consistent with the conclusions arrived at by Scherr, Close, McKagan and Vokos (2012) in their analysis of the representations of energy in scientific discourse, including an analysis of the language of scientists and the visual representations they use (e.g. bar and pie charts, energy level diagrams). They highlight energy as a substance and energy as a location on a vertical scale as two alternative representations of energy used by expert scientists. They refer to these as two "ontologies" for energy: two different broad conceptualizations of the nature of energy. Of course, Scherr et al. are well aware that scientists don't take these conceptualizations literally, but that they metaphorically (consciously or not) ground understanding of this abstract concept in image schematic structures.

Scherr and colleagues point out that the substance metaphor is particularly powerful in that it supports understanding of energy conservation, that energy can be localized, can be located and can accumulate in objects, can be transferred between objects, and can change form. Of course, it is important that in scientific contexts energy is conceptualized as a substance that is not *substantial* – that is it cannot be seen, has no mass and can occupy the same physical locations of actual objects. For this reason, authors often caution that it is best to see this metaphor as involving a *quasi*-material construal of energy (Duit, 1987). But despite this caveat, the substance metaphor of energy is useful, when viewed from a conceptual metaphor perspective, because the inferences generated by the image schemas that make up the source domain of the metaphor are preserved when reasoning about the target domain. These can be laid out explicitly in the following correspondences:

i.	When a substance is transferred from a source to a recipient, the amount of substance possessed by the source decreases and the amount possessed by the recipient increases by the same amount.	When energy is transferred between two components of a system, the energy state of one component decreases and the state of energy of the other increases by the same increment.
ii.	A container gains some amount of a substance, *because* it has received this amount of substance from some source.	The energy state of some component of a system increases to some degree, *because* the energy state of another component (with which it has interacted) has decreased to some degree.
iii.	When an object made of some substance is transformed into another object, the amount of substance is the same before and after the transformation.	When some form of energy is transformed into another form the amount of energy is the same before and after the transformation.

The construal of forms of energy as containers and transformation of energy as movement between containers produces a correspondence of inferences that complements (in fact combines) *i* and *iii* above:

iv.	When a substance is transferred from a source to a recipient, the amount of substance possessed by the source decreases and the amount possessed by the recipient increases by the same amount with the total amount of substance remaining the same.	When energy is transformed from one form of energy to another, the amount of energy no longer in one form is the same as the amount of energy that has come to be in another form; thus the amount of energy is the same before and after the transformation.

These correspondences show the value of the construal of energy as a substance. But it is important to realize that this is just one metaphorical mapping that is useful for specific purposes – namely, understanding energy exchange, transformation and, crucially, conservation. But as Dreyfus and colleagues have argued, the substance metaphor does not provide much support for conceptualizing negative energy (Dreyfus et al., 2014). They have pointed out that the construal of energy state as a point on a vertical scale lends itself well to situations in which negative energy needs to be considered.

The presentation of the metaphorical construal of energy so far has focused on individual conceptual metaphors in isolation of one another. Moreover, linguistic illustrations of the metaphorical mappings have been single sentences or phrases, taken out of context. As mentioned earlier, blending theory (Fauconnier & Turner, 2002) has also been concerned with the description of mapping between conceptual frames, but with attention to the emergence of meanings in specific discursive exchanges, with attention to representational modes beyond language and with attention to the blending of elements from multiple conceptual frames, not just unidirectional mapping from a source to a target domain. Dreyfus, Gupta and Redish (2015) have used the conceptual blending framework to analyze a physics professor's lectures. Their analysis attended to multiple representational modes: language, gestures used by the lecturer and graphical representations drawn on the board while lecturing. Using a conceptual blending framework to examine how the conceptualizations of energy were conveyed by the professor in his lectures, they were able to identify what they refer to as an ontological blend of both the substance and the location construal of energy. They identify this blend in the context of a lecture on the formation and breaking of a bond between atoms. The professor draws on the substance metaphor to conceptualize energy *absorbed* (when the bond is broken) and energy *released* (when the bond is formed). He simultaneously makes use of the ENERGY STATE IS A LOCATION metaphor to conceptualize the change in the energy state of the two atom pair. Dreyfus et al. (2015) present a detailed analysis of the coordination and blending of these metaphors by the professor as he explains the causal connections between the input and release of energy and the change in the energy state of the two interacting atoms. They show how language, elements of the graph drawn on the board and gestures play complementary roles in guiding the projection of conceptual frames into a powerful conceptual blend.

Metaphorical construal of energy transfer as heat

To expand this presentation of the metaphorical construal of the concept of energy in science, I turn to two closely related concepts: heat and entropy. I begin with heat. The understanding of energy transfer metaphorically in terms of a substance is further exemplified in the specific case of the concept of heat, which is the exchange of energy between components of a system as a result of heating (i.e. the transfer of kinetic energy). When explicitly defining heat, scientists will treat heat as a process: heat *is* the *exchange* or *transfer* of energy. But, as Brookes (2006) has documented through a careful grammatical analysis of the use of the noun *heat* in widely used introductory physics textbooks, heat is very often construed ontologically as a substance. That is, even when textbook writers are careful to emphasize the nature of heat as a process when defining heat explicitly they will often write as if heat is a substance, as in the following examples (quoted in Brookes, 2006, p. 114, emphases added):

> "Heat … can be *added to* or *withdrawn from* the gas …"
> "… heat *flows from* …hotter cup …*into* …cooler hand."
> "The heat *rejected* by this engine …"

As Brookes discusses, this substance metaphor for heat is an encoding in modern scientific language of the eighteenth century Caloric Theory of heat, in which heat was explicitly conceptualized as a substance that raises the temperature of a material as it accumulates in it. While attempts to weigh this caloric failed and heating was increasingly associated with motion, conceptualizing heat as a substance (in some sense) persisted well into the nineteenth century. Scientists eventually abandoned any explicit belief in heat being a substance. However, construing it metaphorically as a substance continues to be useful in the context of the need to quantify energy exchange via heating and to track this exchange between components of a thermodynamic system.

Metaphorical construal of entropy and the second law of thermodynamics

The aspect of the concept of energy that has not yet been discussed is the relative usefulness of some forms of energy – i.e. energy can be degraded and thus become less useful; and the idea that while all physical changes conserve energy, some changes are more likely to occur spontaneously than others. If the law of conservation of energy is the *first* law of thermodynamics, the *second* law of thermodynamics dictates that any spontaneous process must occur such that the net result is an increase in the degradation of energy in the universe.

The concept of entropy captures this idea: spontaneous processes occur such that the entropy of the universe increases. Conceptual metaphors are used richly to conceptualize this idea as well. The metaphorical mappings used to construe energy transfer, transformation, and conservation presented above illustrate the systematic nature of the use of metaphor in scientific discourse. An analysis of the metaphors used to construe entropy and the second law of thermodynamics also reveal the systematic metaphorical mappings underlying the diversity of metaphorical expressions used in this scientific domain.

Furthermore, three additional metaphorical phenomena are well illustrated in this case: that different conceptual metaphors are used to construe the same concept in different contexts; multiple conceptual metaphors are coordinated together to support scientific reasoning; and a narrative form of thought can emerge as a result of the coordinated use of multiple metaphors thereby grounding and simplifying abstract and complex chains of scientific reasoning.

The results of two studies reported in Amin, Jeppsson, Haglund and Strömdahl (2012) and Jeppsson, Haglund, Amin and Strömdahl (2013) can be used to illustrate these phenomena. Amin et al. (2012) analyzed widely used university level textbooks that cover the concept of entropy and the second law of thermodynamics to identify the implicit conceptual metaphors used to conceptualize aspects of this domain (Bowley & Sánchez, 1999; Young & Freedman, 2003; Zumdahl, 1998). These textbooks spanned different sub-specializations (physics and chemistry) and degrees of sophistication (introductory university coverage and more mathematized treatments for more advanced students). Moreover, they each covered the topic at both the macroscopic level in which thermodynamic systems are characterized in terms of macroscopic variables, such as temperature, pressure and volume; and the microscopic level where very large numbers of interacting particles and their statistical properties are considered. The study identified the conceptual metaphors that were common to all three textbooks and thus could be considered to be representative of the pedagogical discourse in this domain.

The conceptual metaphors identified were reported as sets of conceptual mappings that were commonly used to construe the concept of entropy and the second law of thermodynamics at the macroscopic level, the microscopic level and the relationship between the two levels. A key finding of this study was that a particularly large number of metaphorical mappings could be identified in the macroscopic treatment of the topic. But despite the many mappings identified, they were mostly sub-mappings (sometimes with elaborations) of either the Location Event Structure or Object Event Structure conceptual metaphors applied to thermodynamic systems. The sub-mappings of the Location Event Structure metaphor were as follows:

16. STATES OF A SYSTEM ARE LOCATIONS ("…the three phases are present *in* thermodynamic equilibrium …")
17. CHANGES IN A SYSTEM ARE MOVEMENTS ALONG A PATH ("…the process *goes from* state 1 … *to* state 2 …")

18. CAUSED CHANGES TO A SYSTEM ARE FORCED MOVEMENTS ("…*driving force* for a spontaneous process is an increase in the entropy …")
19. SPONTANEOUS CHANGE IS DIRECTED MOVEMENT ("…the natural progression of things is *from* order *to* disorder …"
20. SPONTANEOUS CHANGES ARE AGENTIVE (SOMETIMES SENTIENT) MOVEMENTS ("… the second law of thermodynamics … determines the *preferred direction* for such processes …"
21. MAINTAINED STATES OF A SYSTEM ARE BLOCKED (POTENTIALLY MOVING) OBJECTS ("…n and T are *held* constant in this experiment …"
22. A SCIENTIFIC LAW/PRINCIPLE/EQUATION IS A SOCIAL LAW ("…a *forbidden* process would be if all the air in your room spontaneously moved to one half of the room …")

The set of conceptual metaphors above (all sub-mappings of the location event structure metaphor and elaborations of it) produce a coherent system of metaphorical interpretation of the states of thermodynamic systems and how they change. The system is construed as an object in some location that moves in different possible directions; this movement can be blocked, but it will naturally prefer to move in some directions more than others; and those preferred directions will be along paths it is allowed, by law, to follow.

Another (smaller) set of conceptual metaphors are sub-mappings of the Object Event Structure metaphor:

23. ENTROPY IS A POSSESSION ("…every substance *has* a positive entropy …")
24. ENTROPY OF COMPONENT/SYSTEM IS A PART/WHOLE ("The *total* entropy is the sum of the *entropies* of the two systems.")
25. CHANGE OF ENERGETIC STATE OF A SYSTEM (DURING SPONTANEOUS PROCESS) IS LOSS OF A SUBSTANCE (HEAT) ("…the energy it *gives up is transferred to* the surroundings … as heat.")

Here states are construed as a possession/substance, states of components of a system are construed as parts of wholes and changes of state are construed as movement of possession/substance. The above mappings apply this to the construal of entropy as a possession/substance and part/whole and energy state change (during a spontaneous process) as loss of a substance (heat). It is important to note here that this construal of energy transfer as *loss* is a metaphorical construal inconsistent with the use of the metaphor of substance exchange to make sense of conservation of energy. Here *loss* (expressed in the example by "gives up") needs to be interpreted differently. While statements that reflect this mapping are statements about *transfer* they are really standing in for *transformation*. This is not really surprising since we have already seen that forms of energy are construed as locations and energy transformation is construed as movement between locations. The notion of loss ("gives up") is capturing the idea that the energy is no longer "in" a useful form. It might be more precise to state/unpack the underlying mappings (inferred from this analysis) as follows:

26. DEGRADATION OF ENERGY IS TRANSFER OF A SUBSTANCE FROM AN ACCESSIBLE LOCATION TO AN INACCESSIBLE LOCATION

Two additional conceptual metaphors used to construe entropy in macroscopic treatments of the topic are:

27. A MATHEMATICAL FUNCTION IS A MACHINE (WITH OUTPUT SUBSTANCE) ("Our new expression for the entropy *gives* …")
28. CORRELATION IS ACCOMPANIMENT ("The entropy change *associated with* the mixing …")

The first applies a generic metaphor used to construe any mathematical function as a machine (whatever variables it may involve) to the concept of entropy. The result is that entropy is construed in this context as a substance produced by the Function/Machine. The second allows us to construe correlation between the variable entropy with another variable or process as the two entities accompanying one another.

This richness of metaphorical mappings was not found when metaphor use to construe microscopic process was examined in Amin et al. (2012). Only two sub-mappings of the Location Event Structure metaphor were identified, namely:

29. MICROSTATES ARE LOCATIONS ("…the number of arrangements (positions and/or energy levels) *available to a* system …")
30. CHANGE OF MICROSTATE IS MOVEMENT INTO/OUT OF A LOCATION ("…the molecules *go into* solution …")

Finally, three independent metaphorical mappings were identified in the context of relating macro- and microscopic levels of description:

31. RELATING IDEAS AT DIFFERENT LEVELS IS TO CONNECT THEM ("… we will *connect* entropy and the probability [of microstates] …")
32. MACROSCOPIC PROCESS ARE MACHINES THAT PRODUCE/MANIPULATE MICROSCOPIC PROCESSES ("A gas expands into a vacuum to *give* a uniform distribution [of particles in the container] …")
33. PROCESSES OCCURRING AT DIFFERENT LEVELS IS ACCOMPANIMENT ("…the decrease in disorder *associated with* the lowered temperature …")

It is important to remember that the sets of conceptual metaphors identified in the different contexts of the topic of entropy and the second law of thermodynamics by

Amin et al. (2012) were common across three different textbooks varying in their treatment of the topic. These spanned sub-specializations (chemistry and physics) and degree of mathematization of the topic. Thus, these sets of metaphorical mappings seem to be a stable feature of the pedagogical discourse to which learners are exposed when they encounter this topic. I assume here that the ability to use these conceptual metaphors in the appropriate way in particular contexts is an aspect of what students will need to learn. I return to this assumption and discuss some suggestive empirical evidence to support it later when I discuss a study comparing the use of conceptual metaphor to solve problems on entropy by students with different degrees of expertise.

But to provide a basis for that comparison, I turn first to a study that sought to explore how conceptual metaphors are used by individuals with a lot of scientific expertise when solving problems on entropy (Jeppsson et al., 2013). The results of this study can be used to illustrate that multiple conceptual metaphors are used together in a coordinated way (and coordinated with other types of cognitive resources) to support scientific reasoning in specific contexts; and that a narrative form of thought can emerge as a result of the coordinated use of multiple metaphors, thereby grounding and simplifying abstract and complex chains of scientific reasoning.

In Jeppsson et al. (2013), my colleagues and I report on a detailed analysis of a think-aloud problem-solving session in which two PhD students specializing in physical chemistry solve a series of problems dealing with the concept of entropy. For example, the first problem presented to the students was:

> *A beaker contains water at temperature 0 °C and is put in a room of air at a constant temperature of −10 °C, so that a layer of ice forms on top of the liquid water. Describe what drives forward the process of freezing the water.*

One of the claims emerging from the analysis performed in this study was that the abstract scientific reasoning involved in this problem-solving session involves recruiting and coordinating multiple conceptual metaphors. To illustrate this, consider an excerpt from the think-aloud protocol dealing with the first problem. (D1 and D2 refer to the two PhD students; the numbers indicate the turn in the transcript; some turns are not quoted below) (Jeppsson et al., 2013, p. 93–94).

[57] D2: /…/ Well, in this case … er, I guess it's simply that … if *I take heat from* this beaker with water … and *move over to* the room … in principle, then … the partition function in … for the room will increase … more than what *I lose* in the beaker, then …

[65] D2: dS is dQ over T, right …?

[66] D1: Delta S is equal to delta Q over …

[67] D2: T…/…/
[75] D2: So, in principle, that means that if the temperature is zero …
[76] D1: Uhum …
[77] D2: …Kelvin … then *you have* an infinite increase in entropy if *you get a small amount* of heat … and in principle … what I mean with this is that … [starts drawing a graph] now, let's see … delta S as a function of [T] for a certain delta Q, *one gets* something like this … so, maybe … the lower the temperature, the bigger the *entropy gain you get* if *you move some* heat *into* this system … so, that means for our heat bath system here … that if *you move a small amount of* heat *from* the water beaker *out to* the room … then, the entropy in the room will increase more than the entropy has decreased in the water beaker … due to the reason that it is colder in the room …

The analysis of the PhD students' discussion as they solved the problems led to a characterization of the role that conceptual metaphors played in arriving at a problem solution. The analysis sought to characterize the image-schematic source domains of conceptual metaphors as intuitive cognitive resources that could contribute to solving the problem. More specifically, of interest was how the PhD students used conceptual metaphors to construe the physical process under consideration qualitatively and to construe the quantities appearing in mathematical equations they evoked to solve the problem. First, a gloss of what the excerpt above reveals about how the students solved the problem might be helpful.

The students partitioned the system into two components: the water being cooled and the cold air surrounding it. They conceptualized the process of freezing of the water as a transfer of heat from the water to the air. They invoked the quantitative relationship between the change in entropy of some component of a system and the loss or gain of energy from that component as heat. The relevant formula is $dS = dq/T$ (i.e. change in entropy is equal to heat energy loss/gain divided by temperature). They compared the resulting dS for the water and air respectively, recognizing that the water lost and the air gained the same amount of heat but that the temperature of water was higher than the air. This meant that the decrease in the entropy of the water was less than the increase in the entropy of the air. Since the net result is an increase in entropy, this will drive the process forward.

Analyzing the excerpt from the perspective of conceptual metaphor reveals multiple metaphors at work in the students' conceptualization of the problem. Three of them we have seen already from the textbook analyses summarized above, but two of them are new to this context of problem solving. The words and expressions reflecting these conceptual metaphors are marked in italics in the excerpt above. The following five metaphorical mappings were identified (the numbers of the first three identify the mappings with those already mentioned earlier):

5. CHANGE OF ENERGETIC STATE IS MOVEMENT INTO (OR OUT OF) A CONTAINER ("…*take heat from* this beaker …*move over to* the room,"
23. STATE (ENTROPY) IS A POSSESSION/CHANGE OF STATE IS MOVEMENT OF POSSESSION ("…the *entropy gain* you get …")
27. A MATHEMATICAL FUNCTION IS A MACHINE (WITH INPUT AND OUTPUT SUBSTANCE) ("…let's see … delta S as a function of [T] for a certain delta Q …the entropy gain you *get*")
34. A PROBLEM SOLVER IS A MANIPULATOR OF A SYSTEM ("… if *I take* heat from this beaker with water …and *move over* to the water …;" "… if *you move* a small amount of heat from the water beaker out to the room …")
35. A PROBLEM SOLVER IS AN OPERATOR OF A MACHINE ("…the lower the temperature, the bigger the entropy gain *you get* …")

The first three conceptual metaphors (5, 23 and 27) have already been discussed. The last two (34 & 35) are new. A PROBLEM SOLVER IS A MANIPULATOR OF A SYSTEM is reflected in the use of the pronouns 'I' and 'you' to refer to some entity manipulating heat in the physical process under consideration. In this conceptual metaphor, the problem-solver construes herself as actively enacting the transfer of the heat from the initially warmer component of the system (the water) to the colder component (the cold air in the room) (conceptual metaphor 34). This conceptual metaphor is closely linked to conceptual metaphor 5 in which change in energy state is construed as movement of a possession (heat) between the components of a system.

Together these provide a metaphorical construal of the linked changes in temperature of the water and the air in the room. This is the qualitative starting point for making sense of this problem. To make sense of the quantitative part of the problem, the relevant equation was identified, $dS = dq/T$, and given a metaphorical interpretation as a machine (conceptual metaphor 27). This construal of the function as a machine, taking substances/objects as input to give out some other substance/object as output, is then coordinated with the relevant construal of change of energy state as movement of a substance (the input to the machine) and change in the state function entropy as movement of a substance (output).

In addition, conceptual metaphor 35 is a kind of linchpin for this coordination, where the problem-solver herself is manipulating the machine (offering input and receiving output). Notice that conceptual metaphor 5 is common in these two sets and serves to align the qualitative and the quantitative reasoning. Figure 1 provides a schematic illustration of this coordination of conceptual metaphors and the alignment between the quantitative and qualitative reasoning.

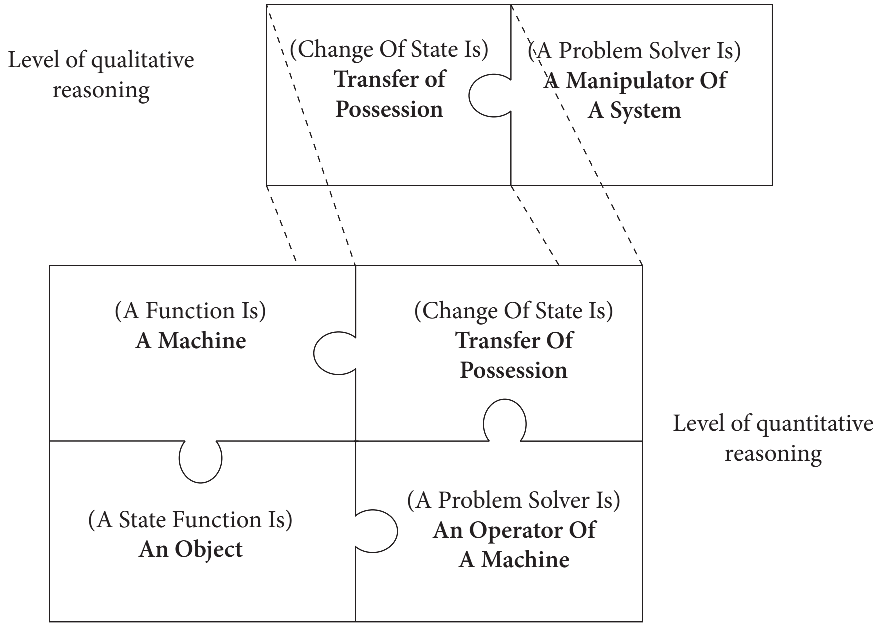

Figure 1. Coordination of multiple conceptual metaphors to align qualitative and quantitative reasoning during problem-solving (figure reproduced with permission from Taylor & Francis (https://www.tandfonline.com/); originally published as Figure 6 (p. 98) in Fredrik Jeppsson, Jesper Haglund, Tamer G. Amin & Helge Strömdahl (2013). Exploring the use of conceptual metaphors in solving problems on entropy, *Journal of the Learning Sciences*, 22:1, 70-120, DOI: 10.1080/10508406.2012.69192f)

One way to think about the coordination of the conceptual metaphors in the problem solution just discussed is that conceptual metaphors are invoked such that sets of source domains combine to create larger, coherent composite source domains. A second excerpt from the same problem-solving session illustrates this further and illustrates how these composite source domains can transform a segment of abstract and complex reasoning into a simpler and more concrete instance of narrative thought. In this excerpt, the PhD students are addressing another problem (Problem 3):

> *Consider a thermally isolated system of an inert gas held in a container by a frictionless piston. Let the gas expand reversibly by moving the piston. What happens to the system's entropy? Does it increase, decrease or remain the same? Justify your answer.*

A reversible process is one that occurs in infinitesimally small increments such that the system is in equilibrium at all times; the reference to the system being thermally isolated means that it does not exchange any heat with the surroundings. Given that both conditions hold $dS = dq/T = 0$ and it can be concluded that the entropy does not change as a result of the expansion of the gas that occurs. A key excerpt from the PhD students' response to this problem runs as follows (quoted from Jeppsson et al., 2013, p. 100)

[488] D2: So, the definition of a *reversible* process actually is that the entropy does not change …

[489] D1: Well, right … [draws a PV diagram] It is that … it's a question of that *one walks along the same line* … if one increases the volume … and then, when one decreases the volume, then …

[490] D2: … *you can get back to* the same state …

[491] D1: Yes, right.

[492] D2: Then you can't have had any entropy losses … because you can never decrease the entropy in an isolated system …

[493] D1: No.

[494] D2: Because if *you are going to be able to get back to the same point*, then you can't increase it either, right, because then you won't get back …

How is metaphor being used in this excerpt (see Jeppsson et al., 2013 for an expanded discussion)? First, notice the language (in italics reflecting the sustained use of a conceptual metaphor that we have already seen: CHANGE OF STATE IS MOVEMENT reflected in the use of *reversible*, *walks along the same line* and *get back to the same point/state.*

Another conceptual metaphor is reflected in the use of the pronouns "one" and "you" (underlined). We saw in the analysis of the previous excerpt two conceptual metaphors reflected in the use of pronouns: A PROBLEM SOLVER IS MANIPULATOR OF A SYSTEM and A PROBLEM SOLVER IS AN OPERATOR OF A MACHINE. Here we find another conceptual metaphor: A PROBLEM SOLVER IS A SYSTEM. That is, the pronouns "one" and "you" above are used with expressions in which the change of state of the system is construed as movement, and the pronouns refer to the entity doing the moving. The composite source domain involved in using these two conceptual metaphors involves an *agent walking along a path freely, able to move back and forth along that path unobstructed.*

This composite source domain is a brief instance of a narrative mode of thought, in which an agent is behaving to achieve some goal in a physical setting. To see the conceptual work that this (narrative) source domain is doing we should notice that metaphorical language in this excerpt is used while the problem-solvers are drawing and referring to a pressure versus volume (PV) graph. Thus, we have a situation where the pronouns "one" and "you" are simultaneously referring to the problem-solver, the physical system of the expanding gas under consideration and the points on the PV graph.

The mini-narrative is standing in for a complex chain of reasoning linking the qualitative consideration of an expanding gas, the quantitative graphical representation of the relationship between the variable of pressure and volume characterizing this gas and the problem-solver himself reflecting on the qualitative and quantitative aspects of the problem. Whereas we saw metaphor being used to *align* qualitative and quantitative reasoning in the discussion of the previous excerpt, here metaphor is used to *integrate* the two types of reasoning.

The challenge of learning to use metaphorical construals of the scientific concept of energy

Up until this point in this chapter, I have documented the use of conceptual metaphor to construe aspects of the concept of energy and the related concepts of heat and entropy in scientific contexts. We have seen that underlying the very many metaphorical expressions used in pedagogical discourse dealing with these concepts are sets of conceptual metaphors that are often sub-mappings of more general conceptual metaphorical mappings.

We have also seen that different conceptual metaphors are used to construe different aspects of a concept (e.g. *transfer*, *transformation* or *conservation* of energy), different levels of description of a topic (e.g. *macroscopic* or *microscopic* treatments of thermodynamic systems and the relationship between them), and different contexts (e.g. textbook presentations versus oral problem solving). Moreover, we have seen that advanced problem-solving involves the coordination of multiple conceptual metaphors in such a way that source domains combine coherently to create composite source domains.

An important question that arises from all this is 'does all this matter for learning?' After all, all that I have done so far is describe patterns of language use in various scientific contexts. The theory of conceptual metaphor, as developed by Lakoff and Johnson (1980, 1999) and others was a claim about *conceptual* mappings between domains that can be *inferred* from *patterns* in metaphorical expressions. The assumption here is that without some underlying conceptual phenomenon at work, we should not expect the systematicity that is in fact observed in language use. I endorse this assumption in the context of scientific discourse as well.

But to confirm the conceptual significance of the phenomenon of conceptual metaphor in scientific discourse and to characterize its contribution to scientific expertise and its acquisition more evidence is needed. In this section, I discuss a number of different sources of evidence. The first is a comparative analysis of the use of conceptual metaphors in solving problems on entropy across different levels of expertise. The second is a description of the conceptual metaphors implicit in everyday use of the word *energy* and how the source domains of these metaphors map onto the alternative conceptions of energy held by middle and high school students learning science in the context of formal education. Third, I summarize the results of a study that provides evidence of a link between the substance metaphor of heat and university students' mistaken treatment of heat as a state function while solving thermodynamics problems. Finally, I discuss evidence that, while a substance construal of heat is implicit in everyday English, this can both support and hinder students' reasoning in different scientific contexts. The framework of conceptual blending helps show how different aspects of this metaphorical construal of heat as substance can emerge selectively in different contexts.

Changes in the use of conceptual metaphors with the acquisition of expertise

In Jeppsson, Haglund and Amin (2015), we asked a pair of undergraduate chemistry students to think aloud together while they solved the same problems solved by the two PhD physical chemistry students previously discussed in Jeppsson et al. (2013). The undergraduate students' problem solving session was transcribed verbatim and the use of conceptual metaphors and their role in problem solving were described. We then compared the use of conceptual metaphors by the undergraduate and PhD students. In this study, we were also interested in the distinct roles of propositional representations (such as linguistically or mathematically expressed scientific principles) and the non-propositional (i.e. analogical) representations (such as the image schemas that constitute the source domains of many conceptual metaphors). Our comparative analysis of the problem solving at these different levels of expertise revealed a number of differences in the use of conceptual metaphors.

First, the undergraduates made much less use of conceptual metaphors in their problem-solving attempts. Second, when they did use conceptual metaphors this use was not 'productive.' That is, while the PhD students used conventional metaphors widely found in textbooks (e.g. CHANGE OF STATE OF A SYSTEM IS MOVEMENT) they combined these conceptual metaphors with others to create novel composite source domains in specific contexts and they used novel metaphorical expressions that reflected the same underlying conceptual metaphor (e.g. 'If I *walk* along the line). The more productive use of conceptual metaphors by the PhD students was also reflected in the more frequent metaphorical use of pronouns in which the problem solver is construed as interacting with or even identified with the thermodynamic system under consideration. As discussed above, this use of metaphor was strategic in simplifying and concretizing (in narrative form) a highly abstract chain of reasoning that required connecting qualitative and quantitative aspects of the reasoning.

This use of metaphor was not observed in the undergraduates' problem solving attempts. Thus, the few uses of conceptual metaphors by the undergraduates were isolated and highly conventionalized repetitions of metaphorical expressions to which they would have been exposed in lectures and textbooks. One could sum this up by saying that the undergraduates seemed not to have yet learned to use the conceptual metaphors productively like those with greater expertise in the domain.

In Jeppsson et al. (2013), we noted another indication that learning to use conceptual metaphors is implicated in conceptualizing and reasoning about entropy. In that study, we discussed an explicit hesitation among the PhD students as they discussed the expansion of a gas in a thermally isolated piston. The students did initially provide an accurate macroscopic interpretation of the problem and drew the correct conclusion that the entropy of the gas did not change. However, after providing this response they commented that the conclusion was not intuitive (Jeppsson et al., 2013, p. 95).

[507] D1: It's always strange to think that [the entropy] is the same … but, well … I guess that's what it is … it [the problem solving approach] goes straight to the entropy … that *it would be presupposed that one gets more locations to be in …*

[508] D2: Uhum … what I think happens there … is that you … if you get enthalpy losses, that turn into entropy …

[509] D1: Uhum … that you, well … lose in energy, there … then you get the entropy … well, it … *one maybe gains on larger volume, but one loses on not having accessible … all the energy states …*

[510] D2: Uhum …

[511] D1: And hence … the entropy is unchanged …

This exchange is full of metaphorical expressions that are all interesting to analyze in their own right. But what is of particular interest for the argument being developed in this section is that it provides evidence of the challenge of metaphorical mapping. At a microscopic level, change of entropy is linked to changes in the number of microstates that could be occupied by the system. The MICROSTATES ARE LOCATIONS conceptual metaphor is implicated here. However, the microstates potentially "available" to a system are not just spatial, involving the locations occupied by the particles that make up the system. Energy states also need to be considered. What the exchange above reveals is that the idea that entropy is linked to accessible microstates is intuitively related to the change of volume of the gas because an increase in volume provides the system with "more locations" to be in. That is, the significance of spatial/configurational microstates is obvious, and would lead one to conclude that change of volume results in an increase in entropy.

While less intuitive, the students are able to push their understanding of "accessible microstates" to include "energy states." Crucially, this involves a metaphorical mapping: energy states are construed metaphorically as locations. The excerpt above is revealing that some cognitive work is being done to guide this mapping. Their principled reasoning at the macroscopic level and their confidence in the conclusion that the entropy change should be zero has guided these students in the metaphorical mapping required at the microscopic level.

Conceptual metaphors in everyday language and learners' alternative conceptions

I turn next to another indication that conceptual metaphors are implicated in developing scientific understanding of the concept of energy. What is involved here though is the use of everyday metaphors and their role in shaping learners' alternative conceptions en route to their developing scientific understanding. In Amin (2009), I argued that the alternative conceptions that have been repeatedly identified in science education research on learner conceptions can be traced to conceptualizations implicit in everyday language, much of which is metaphorical.

Many of students' conceptions of energy at different educational levels can be traced to a relatively small set of conceptions originally identified by Watts (1983). He described six different conceptions of energy: (a) energy as a causal agent stored in an object which is needed for its activity; (b) energy as an 'ingredient,' with some triggering event leading to its release (c) energy as activity or movement itself, not its cause; (d) energy as the output or byproduct of some process; (e) energy as a generalized fuel that makes things go, and (f) a flow or transfer conception of energy. Many studies since Watts (1983) using a variety of different methods have repeatedly identified subsets of these six conceptions (see Amin, 2009 for review).

In a conceptual metaphor analysis of the everyday use of the word *energy* (reported in Amin, 2009), I identified a number of literal and metaphorical construals of energy implicit in lay language use. These correspond quite readily to the six conceptions of energy found in the science education literature. This correspondence is summarized in Table 1. In his account of cognitive development in cultural context, Tomasello (1999) points out that much (if not most) of our conceptual representations cannot be derived from direct interaction with the physical and social environment, but originate in the subtle perspectival options that language offers the developing child and language user. He draws on the cognitive linguistics literature to illustrate the range of construal options implicit in natural language, including metaphorical construals, that can shape conceptual representations. While not conclusive evidence, the close correspondence between the construals of energy implicit in everyday language and students' alternative conceptions repeatedly identified in the literature suggests that these language-based construals might be the source of these conceptions.

But how does this relate to learning the *scientific* concept of energy? First, the conceptions that students hold as they encounter formal instruction constitute

Table 1. Correspondence between construals of energy implicit in everyday language and students' alternative conceptions of energy. Conceptions a-f are from Watts (1983) and are described above).

Language-based construals	Illustrative phrases	Corresponding conceptions [from Watts (1983)]
Literal		
Materials (e.g. coal, oil) and food are sources of energy	Some fat is necessary to supply the body with a ready *source of* energy	Conception (b)
Energy as a resource	*Stores* … energy *to help you* run faster	Conceptions (a) & (e)
Energy is activity	…victory was certain if other members … *showed* similar energy	Conception (c)
Metaphorical		
ENERGETIC STATE IS A POSSESSION	She has never *got much* energy in the morning as you know.	Conception (a)
CHANGE IN ENERGETIC STATE IS MOVEMENT OF POSSESSION	When they feel *drained of* spiritual energy the students go there and lie on the floor.	Conception (f)
CAUSED CHANGE IN ENERGETIC STATE IS TRANSFER OF POSSESSION	The fame thing … isn't where creative energy *stems from*.	Conception (d)
ENERGETIC STATE IS AMOUNT OF MATERIAL IN A CONTAINER	He appeared happy, *full of* energy and suppressed excitement.	Conception (b)
ENERGY IS A RESOURCE	He's been *living on his reserves of* nervous energy.	Conceptions (a) & (e)
ENERGY TRANSFER IS FORCE	But while Clinton is *bursting with* energy now, what toll will the next four years take if he enters the White House?	Conception (b)
MORE ENERGETIC IS UP; LESS ENERGETIC IS DOWN.	… it represents the *lowest* state of emotional energy, as well as physical and mental energy.	---

the conceptual resources they will draw on as they construct their more abstract scientific understanding. These resources may both support or hinder learning the scientific concept; either way, they are implicated in the learning process. In turn, tracing these resources to construals implicit in everyday language in turn implicates everyday language in the learning process. Moreover, comparing the conceptual metaphor analyses of everyday and scientific use of the term *energy* reveals a great deal of overlap in the source domains used to construe energy in lay and scientific contexts. The similarity in the source domains and the fact that many of these are image schematic, suggests a significant degree of continuity across the learning process. It shifts the burden of understanding the process of learning the concept of energy to characterizing how the learner learns to apply the right construal in the appropriate context.

Errors in student reasoning and the substance metaphor of heat

As a third indication that conceptual metaphors are implicated in the process of learning, I turn to the concept of heat; specifically, its metaphorical construal as a substance. As discussed above, scientific purists will insist that heat is a process: it is the exchange of energy via the process of heating. But also, as pointed out above, the language of science metaphorically construes heat as a substance-like entity via grammar and metaphor. Does this pervasive metaphor impact student learning?

Brookes and Etkina (2015) have recently provided evidence that it is at least *connected* to student learning. In this study, three kinds of data were collected from 10 undergraduate physics students who had already been introduced to some thermodynamics at the university level. The students were presented with a description of an ideal gas in a piston surrounded by a jacket of water and the steps of a thermodynamic cycle that the gas underwent. At each step, the students were presented with questions such as 'was there net work done on/by the gas?' 'is there a net flow of energy between the gas and the water?' and 'does the total kinetic energy of the gas molecules increase?' They were asked to explain their answers. The researchers analyzed the accuracy of students' responses and their reasoning. A second type of data was the language they used to talk about heat while responding to the questions. The extent to which a substance ("caloric") metaphor was used was documented. Third, participants were explicitly asked to define heat.

A key finding of this study was that students with substance/caloric definitions were more likely to use a substance metaphor implicitly while talking about heat and were also more likely to incorrectly treat heat as a state function while reasoning. That is, they concluded that if a gas was compressed but with the temperature remaining constant, the net heat transfer should be zero. This conclusion is incorrect because as a gas is compressed the total kinetic energy increases; for the temperature to remain constant there must be some transfer of energy to the surrounding water jacket. Students who reasoned incorrectly were treating temperature as a measure of the amount of heat in the gas, thus treating heat as a substance, and giving it the status of a state function. Brookes and Etkina resist making a strong causal claim that it is students' exposure to the material substance language that is affecting their reasoning. They acknowledge that it is possible that an underlying conception of heat (independent of the language to which they are exposed) may be giving rise to both the language they use and their reasoning about the thermodynamic system. They suggest that some kind of bi-directional interpretation of the effect of language and underlying conceptions of heat is most likely.

Brookes and Etkina's bi-directional interpretation seems reasonable but of course, more empirical research is needed to tease apart competing interpretations of these findings and to fine-tune our understanding of the influence of language, and its implicit metaphors, in shaping an understanding of the scientific concept of heat. Relevant evidence would be whether young children exhibit a substance view of heat before they have been exposed to scientific language. The literature suggests a substance view of heat is very rare among very young children (about 4–6 years of age) but it starts to appear after that age, especially when language is used that prompts for it (Haglund, Jeppsson, & Andersson, 2014).

These findings do support the suggestion that language plays some role in shaping a substance conception of heat. However, what complicates the story is the role of everyday language. In Amin (2001), I analyzed the conceptualizations implicit in the grammatical constructions and metaphors used to talk about heat in everyday language. The analysis shows that a substance-like conception of heat is deeply entrenched in everyday English. If exposure to language with this implicit conception shapes children's conceptions it is surprising that it is not until about the age of 7 that this substance conception of heat can be elicited. More research is certainly needed to clarify the role that construals implicit in language play in shaping conceptions of heat at different ages and educational levels.

I conclude this discussion of the substance metaphor of heat and student reasoning by pointing out what a conceptual blending perspective can alert us to, namely the role that the context of reasoning can play. In Amin (2001), I showed how a high school student reasoning about heat-related phenomena can draw productively on the substance metaphor in one context and unproductively in another. I argued that students, having been exposed to everyday language have internalized a lay model of heat that includes the notions that heat can be localized, that it can move from one location to another and can have a causal effect such as raising the temperature of an object. However, that model does not include heat as *substantial*, in the sense that it has weight and cannot occupy the space occupied by another object. The lay model of heat implicit in everyday language has some features of the substance ontology but not all. In a conceptual blending analysis of students' reasoning in a variety of contexts, I found that a student could make productive use of heat as a substance in the context of reasoning about heat conduction in a metal rod, but reasoned incorrectly when reasoning about how thermal insulation works. In the first context a construal of heat as substantial was not invoked but in the second it was.

The conceptual blending analysis indicates why this might be by suggesting that the substantive construal of heat *emerged* in the context of reasoning about insulation. This illustrates one distinctive contribution of the blending framework: that it allows us to characterize mappings between conceptual domains that emerge on-the-fly during reasoning. In contrast, the perspective of conceptual metaphor tends to direct the analyst to identify conventional mappings that are entrenched in language use. Therefore, the perspective of conceptual blending can be a very useful complementary lens to reveal the relative contributions of stable and contextually emergent conceptualizations to learners as they attempt to make sense of natural phenomena when learning science.

Conceptual metaphor and teaching the concept of energy

So far in this chapter, I have surveyed the range of conceptual metaphors used in scientific discourse to conceptualize the concept of energy and the related concepts of heat and entropy. I have shown that despite this apparent diversity of metaphors, a conceptual metaphor analysis reveals underlying systematic mappings between a relatively small number of image-schematic source domains and aspects of these abstract scientific concepts. I have also suggested that an aspect of scientific expertise is to use multiple metaphors flexibly to conceptualize different aspects of these concepts in different contexts. In addition, I have illustrated that subtle coordination of multiple metaphors can support scientific problem solving, in particular, by coordinating qualitative and quantitative reasoning and by concretizing and simplifying chains of abstract reasoning.

I have also discussed that learning how to use conceptual metaphors seems to be an aspect of developing scientific expertise: that the use of conceptual metaphors to solve problems on entropy varies across levels of expertise; alternative conceptions of energy formed early during instruction correspond to the construals (including conceptual metaphors) implicit in everyday language; and that errors in reasoning about heat exchange in the context of thermodynamic processes is linked to the substance metaphor of heat. The issue addressed in this final section is what implications for formal instruction can be drawn from these findings.

I organize this discussion of instructional implications around various aspects of the findings discussed so far – namely, the *implicit* nature of conceptual metaphors in scientific discourse; that understanding a scientific concept involves invoking a number of *particular* image-schematic source domains strategically; and that a challenge of construing scientific concepts metaphorically is to perform a scientifically sanctioned mapping of the source domain to the target. I discuss the instructional implications of each of these points in turn.

The implicit nature of conceptual metaphors

Without the development of the theory of conceptual metaphor and systematic analyses of lay and scientific language from this perspective, many of the metaphorical construals of energy described in this chapter would not have been recognized. The language that has now been shown to reflect underlying conceptual mappings was at best dismissed as just a linguistic phenomenon and at worst not recognized as metaphorical at all. Scientists, textbook writers and teachers typically use this language without any awareness that they are using metaphor. And yet, as I have argued, these metaphors are used systematically, coordinated meaningfully to achieve cognitive goals, and seem to be a feature of scientific expertise. So what are the instructional implications of this implicit aspect of expertise?

Research on learning has, for some time, recognized that there are elements of expert competence that are unarticulated and embedded in practice (Lave, 1988; Rogoff, 1990). From carpentry to theoretical physics, these elements can be implicit in the experts' use of material and symbolic tools, in the structure of the practice itself which has been shaped by the history of the trade or profession, or implicit in the cognitive procedures required for successful performance since it is in the nature of how the brain works that many (if not most) processes do not surface to the level of awareness (Evans, 2003). This implicit aspect of expertise usually cannot be articulated and conveyed explicitly via a traditional instructional format relying on transmission from teacher to learner. Participation, albeit peripheral at first, in the real practices of the trade or profession is needed. Therefore, learning to use conceptual metaphors to construe concepts like energy, heat and entropy in the way that scientists do will require exposure to real expert discourse in the context of cognitive apprenticeships (Brown, Collins & Duguid, 1989) across a range of reasoning contexts that are important in the domain. Take the metaphorical use of pronouns by scientists described earlier as an example. We saw that these metaphorical construals played the subtle but important roles of integrating qualitative and quantitative reasoning and simplifying complex chains of reasoning. How would someone learn these skills? The kind of conceptual mappings and coordination involved are much too complex for a teacher (even with the unreasonable assumption that they were aware of them themselves) to articulate explicitly to a learner. Instead, learning such skills would most likely come from exposure to a teacher thinking aloud and through the teacher scaffolding the learner's thinking and language use through guided problem-solving.

This chapter has shown that scientific thinking about energy includes a number of implicit skills involving conceptual metaphors: to construe thermodynamic systems at different levels of description (macroscopic and microscopic) and relate these levels; and to align and coordinate of qualitative and quantitative reasoning sometimes involving the use of a variety of representational tools. The research discussed here has not surveyed systematically the range of reasoning contexts that span the variety of ways in which conceptual metaphors are used to construe the concepts of energy, heat and entropy. This kind of research is needed, however, if our understanding of the use of conceptual metaphors to construe these concepts is to translate into the design of effective learning environments. With the range of reasoning contexts involving the skillful implicit use of conceptual metaphors documented, instructional designers would be able point to the range of contexts in which scaffolding of learner thinking and talking would be of value.

While more research of the kind just mentioned is needed, this discussion of the instructional implications of the implicit nature of conceptual metaphors can be used to evaluate a pedagogical proposal that has been discussed in the science education literature. I mentioned earlier that heat is defined as energy *exchange*; that is, technically, heat belongs to the ontological category of process. However, as we have seen already, the metaphorical construal of heat as a substance is pervasive in scientific discourse. Thus, there is an ontological inconsistency between what heat *really is* as explicitly defined and the ontology construed implicitly through scientific language.

This inconsistency has been seen as a pedagogical problem and it has been proposed that the substance metaphor of heat should be avoided in textbooks and instruction (see Brookes, 2006 for discussion). Given the pervasive use of conceptual metaphor in scientific discourse dealing with the concepts of energy, heat and entropy documented in this chapter, I suggest that it is clear this proposal is wildly unrealistic. Implicit use of conceptual metaphor, often resulting in ontological inconsistency, is just a fundamental feature of how language works and subtle construal shifts are an inherent part of communication and reasoning in science (see also Amin, 2009, 2015; Gupta, Hammer, & Redish, 2010; Jeppsson et al. 2013). Pedagogical strategies need to embrace this fact, not try to avoid it.

Invoking particular source domains strategically

A conceptual metaphor analysis of how the concepts of energy, heat and entropy are expressed in scientific discourse identifies the specific image-schematic source domains that are used to conceptualize various aspects of these concepts in various contexts. Since image schemas are simple knowledge structures derived from sensorimotor experience early in life, they can be assumed to be available to all learners in any context of formal instruction. They are, therefore, readily available cognitive resources the learner can use to make sense of abstract scientific concepts. The pedagogical challenge, therefore, becomes guiding learners to invoke the right image-schemas at the right time. Apprenticeships in practice can help, as just mentioned. But more can be done to design effective learning environments to achieve this goal.

To start with, it is very useful to know the range of image schematic resources learners are already drawing on to conceptualize energy, heat or entropy at a particular point in their learning. Analyzing the language used by learners in classroom settings or as they explain natural phenomena and solve scientific problems can reveal the image schematic resources they have. A conceptual metaphor perspective can provide a systematic way of conducting such analyses. Lancor has used this approach to identify the resources university students have for conceptualizing energy (Lancor, 2013, 2014, 2015). Using an assessment framework of six different conceptual metaphors of energy, all variations of a substance construal of energy, she catalogues the construals of energy used by students taking introductory college physics and an interdisciplinary science course. She also uses the framework to compare students' construals of energy across a variety of disciplinary and topical contexts. This kind of information can serve as a starting point for instruction because it informs the teacher if students are not drawing on the needed range of conceptual resources and if their application of the resources they do have is problematic in some way.

Conceptual metaphor analysis of how a concept is expressed in scientific discourse can also inform specific instructional strategies; in particular, it can inform what visual representations and instructional analogies are likely to be effective when teaching the concept. In their Energy Project, Scherr and colleagues have honed in on the key role that the substance metaphor of energy plays in scientific understanding of energy (Close & Scherr, 2015; Scherr, Close, Close, & Vokos, 2012a; Scherr et al., 2013; Scherr, Close, McKagan & Vokos, 2012). As we have seen, the object event structure metaphor plays a central role in the conceptualization of energy where energy states are construed as possessions/substances, changes in energy states are construed as movement of a possession/substance and caused changes are construed as forced movement of a possession substance.

This set of conceptual mappings is further elaborated such that the energy/substance is construed as a resource for various outcomes. Moreover, and crucially, construing energy as a substance provides a sound intuitive understanding of the conservation of energy across various physical transformations. Scherr and colleagues have exploited the centrality of a substance construal of energy when teaching university students and conducting professional development with science teachers. They have used various representations – such as energy "cubes" and the human body itself in a learning environment they refer to as Energy Theater – to embody the energy as substance metaphor. They have documented success with these strategies in deepening learners' understanding of the concept of energy. The substance metaphor of energy has also served as an anchor for a novel curricular reorientation in the teaching of introductory university physics (Brewe, 2011).

The selection of instructional analogies is another well-known strategy in teaching for conceptual understanding. By "instructional analogies", I am referring to analogies teachers or textbook writers explicitly bring up in their effort to teach a challenging concept. The challenge of selecting the source domain of the analogy is of finding one with relationships between the various component ideas that would really help restructure understanding in the difficult target domain. But all analogies can potentially mislead. The intended mapping between source and target domains can, in principle, be helpful. However, there are always aspects of a source domain that should not be mapped to the target. Moreover, analogies can vary in how many of the relations between concepts in the target domain are captured by the source domain. Throughout this chapter, I have been discussing mappings between source and target domains used to conceptualize aspects of the concept of energy. But the mappings discussed have been those that are implicit in the language of science in this domain and are only recognized after careful analysis. The question that arises here is how the choice of explicit instructional analogies by teachers and textbook writers relates to the mappings of the various conceptual metaphors implicit in the scientific discourse in the domain.

What instructional analogies are most effective to teach the concept of entropy has been debated in the literature (see Amin et al., 2012 for review). A popular textbook analogy is Entropy as Disorder where a system is said to change spontaneously in a direction from a more ordered (lower entropy) state to a less ordered (higher entropy) state. A rich discussion of the merits and drawbacks of this metaphor can be found in the literature (see Lambert, 2002; Leff, 2007; Styer, 2000). One advantage of the metaphor is to provide a vivid mnemonic for capturing the direction of spontaneous change of a thermodynamic system (from less to more entropy/disorder). It also gives an intuitive appreciation for the statistical aspect of the concept of entropy: there are many more ways for a collection of objects to be in disorder as opposed to ordered; thus, disorder is just more statistically likely. A problem with the analogy, however, is its highly spatial nature. Extending disorder to energy states is not intuitive and we have seen that relating entropy to energy states (not just configurational states) is a challenge.

Another problem with the disorder analogy is seen when we compare the mapping involved in the entropy as disorder analogy to the pervasive Location Event Structure metaphor. Disorder refers to haphazard spatial arrangement of objects – e.g. objects scattered randomly around a room as opposed to neatly arranged in drawers and on shelves. When we think of *change* using this analogy we think of a transition from order to disorder; we imagine neatly ordered objects getting scattered around. While this analogy provides a vivid illustration of entropy and the second law of thermodynamics, it does not capture the location event structure mapping which pervades scientific discourse on the topic. That is, the MICROSTATES ARE LOCATIONS conceptual metaphor, and related sub-mappings, involve mapping complex configurational and energetic states to single locations. The disorder analogy does not help with this.

Consider in contrast, ENTROPY IS FREEDOM. A system locked into a rigid, ordered structure is not free; it does not have many configurational or energetic options. Increasing entropy is greater freedom; more energetic states and configurations can be accessed. The notion of freedom is generative of many intuitive inferences that are very consistent with the scientific concept of entropy and mappings are consistent with the sub-mappings of the Location Event Structure conceptual metaphor used to construe entropy and the second law of thermodynamics. In sum, consistency with the mapping of the conceptual metaphors implicit in scientific discourse can be used to judge the relative merit of two instructional analogies. Entropy as Freedom wins out over Entropy as Disorder on this criterion (see Amin et al., 2012 for an extended discussion).

We can argue then that the Entropy as Freedom analogy is a promising choice to guide the strategic deployment and mapping of a useful image schematic source domain that can help learners develop an understanding of entropy. Moreover, we have seen that multiple conceptual metaphors are needed to construe a particular concept: different metaphors are useful for different aspects of a concept and in different contexts. The selection of explicit instructional analogies is not a matter of choosing the *best* one, but selecting the appropriate set of analogies that allow learners to effectively understand the various aspects of a concept, and avoid erroneous interpretation of misleading aspects of some analogies (Spiro et al., 1989).

Mapping source domains to target concepts appropriately

In this final subsection, I turn briefly to the details of the mapping between source and target domains of conceptual metaphors and the implications of these details for instruction. The clearest example seen earlier was the over interpretation of heat as a substance leading university students to treat heat as a state function. The substance construal of heat is useful for conceptualizing *transfer* of energy via heating. But as we saw, it can lead to incorrect conclusions when thermodynamic systems are considered statically, or when initial and final states are compared. Moreover, we saw that mapping locations to energetic states, not just configuration states, can be challenging.

An analysis of learning difficulties in terms of the challenge of making the right mappings between a source and target domain can contribute to instruction. Specifically, it can alert teachers to specific problems learners might face and suggest points of focus for classroom discussion. Indeed, it has been well documented for some time now that teaching scientific concepts effectively can often require alerting the learner explicitly to potential erroneous conceptions that may initially appear intuitive (Amin & Levrini, 2018; Amin, Smith, & Wiser, 2014).

Developing “metacognitive awareness” of problematic intuitive conceptions helps the learner take control of the concept learning process (Sinatra & Pintrich, 2003; Smith, 2018). The application of this idea to the challenge of learning to use conceptual metaphors in science would involve, as we have seen, developing awareness of the metaphorical nature of much of scientific language and awareness of specific errors of mapping between source and target domains that might hinder understanding. Listing this instructional implication is an acknowledgment that implicit learning via exposure to the discourse skills of scientists and guided participation in scientific reasoning and problem solving cannot be the only pedagogical strategy where learning to use conceptual metaphors in science is concerned. There will be times when explicit reflection on scientific language and how it might mislead will be necessary.

Conclusion

In this chapter, I have tried to show that metaphors are pervasive and patterned in scientific discourse dealing with the concept of energy, and the related concepts of heat and entropy. One conclusion from this line of work is that the theories of conceptual metaphor and blending can be useful tools to characterize features of scientific discourse and associated patterns of thought. We have seen that despite the vast numbers of metaphorical expressions that can be found in scientific discourse on energy, we can discern substantial systematicity in the mappings that underlie these expressions. We have also seen that scientists construe the different aspects of the concept of energy in distinct ways, employing systematically a collection of different conceptual metaphors. Moreover, when reasoning or solving problems, they coordinate multiple conceptual metaphors creating coherent, simplifying interpretations of the qualitative and quantitative components of the problems they tackle.

Since the theories of conceptual metaphor and blending complement each other – one focusing on characterizing conventional conceptual mappings and the other capturing conceptualizations that emerge in particular contexts of reasoning and communication – they draw attention to both stable and more flexible features of scientific discourse and conceptualization. Conversely, applying these theoretical tools to the domain of scientific discourse, as discussed in this chapter, shows the value of these theories more generally as analytical tools to investigate human language and thought. This is especially true when they are used to analyze metaphorical expressions, not as single isolated sentences, but as collections of metaphorical construals coordinated together to achieve particular discursive goals.

This perspective on scientific discourse has also been rewarding in providing a way to diagnose the difficulties that learners face when learning science. We have seen evidence suggesting that coordinating multiple metaphors when reasoning is a skill that learners need to develop. We have also seen that the metaphors implicit in everyday language and in the language of science itself, while often helpful, might lead to problematic alternative conceptions that hinder learning.

All this offers clues for instruction. First, since the use of conceptual metaphor is implicit and pervasive in scientific discourse and thought, it is unrealistic to think that problematic metaphors can be avoided. Instead, instruction can help learners use them appropriately through exposure and guided reasoning. Second, documenting the various conceptual metaphors scientists use to construe scientific concepts provides a lens through which to analyze learners' discourse so as to identify the resources they have and those that they lack. It also gives us a way to evaluate the relative merits of candidate explicit instructional analogies. Third, particular mappings between source and target domains may pose particular challenges for learners. These could be addressed explicitly in instruction by inviting learners to consider the metaphorical nature of the language of science and alert them to problematic interpretations of these metaphors. Overall, I have used the cluster of concepts energy, heat and entropy as a case study to illustrate that if we want to use metaphors and analogies to communicate about or teach a given domain effectively we will need coordinated analyses of the use of metaphor across the different contexts of science, learning and instruction.

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PART II

Metaphor in science popularization – concepts of biology and biochemistry

CHAPTER 4

Metaphor and the popularization of contested technologies

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This contribution analyzes metaphors in expert bioscientific texts on reproductive technologies from cloning to pre-implantation genetic diagnosis in German print media during the time when, according to some German journalists, restrictive attitudes seemed ripe for change. The study uses systematic metaphor analysis to investigate the *functional* content of metaphors for those producing a text. It shows how conventional metaphors contribute to the popularization of science, as they bring new reproductive technologies into the realm of our everyday experience. For scientists, this work shows the fine line between explanatory use of metaphors and distortions which can harm the reputation of science. It may foster a nonscientist's ability to interpret metaphors in the production of hope in the promise of new technologies.

Keywords: ethics, human biotechnology, magazines, high quality newspaper, systematic metaphor analysis, functional content, expert authors, context specific analysis, cross domain mapping, semantic transfer

1. Introduction

Metaphors are ambivalent and powerful tools of science and used and reflected as such since Baconian times. There is a consensus not only within this anthology but also espoused within philosophy, psychology, science and technology studies that, within the natural sciences, metaphors play very important *educational* roles (e.g. Cooke & Bartha, 1992; Gentner & Grudin, 1985; Gentner & Jeziorski, 1993; Hesse, 1966; Keller, 1995; Lakoff & Núñez, 2000; Maasen & Weingart, 2000;). Metaphors are often used in areas where meaning is otherwise hard to convey (Schmitt, 2003). They frequently appear in communication between experts and laypeople and are thus a common ingredient in media publications about the natural sciences.

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As metaphors are an essential tool in all complex communicative situations (Johnson, 2010), they play a leading role within the public media and popular science. When topics of natural science and medicine are transmitted to the broader public, the communicative situation between speaker and audience is often understood as similar to that within schools or universities: for a long time at least it was assumed that 'the public' lacked sufficient knowledge about the natural sciences and technology, especially when taking a specific (and in particular a critical) position regarding the natural sciences (Marks, 2009). It was assumed that the public simply required proper information in order to adopt a more positive stance.

When new technology needs to be explained to a lay audience by means of illustration and modeling, this often comes in combination with humor and mostly aims at convincing the audience of the benefits of this technology (Semino, 2008; Herrmann, 2013). We find such a situation whenever new technology is presented to the public with the aim of a discursive change in favor of these developments, as for instance the introduction of alternative energy, green revolution, education reform or space exploration. Expert discourse going public about contested technology shows a very specific use of metaphors, as this study reveals.

Background to the exemplary study

As a case study, this chapter explores an international expert discourse in German quality print media at a particular historical juncture in Germany: when a political shift from a restrictive to a more open position towards new reproductive technologies seemed possible to some German journalists. Around the year 2000, after a change in political leadership in Germany from the Christian Union to Social Democrats, the new German chancellor tried to propagate Germany as an ideal place for biotechnology industries, while also the German Medical Chamber presented a position paper, which was critically received, urging a new and more liberal law on new reproductive technologies. In this context, the international, mainly Anglo-Saxon, public scientific culture exposed in the articles I will analyze, coincided with a generally critical German discourse on reproductive technology. This situation provoked texts about future reproductive possibilities very rich in metaphoric use.

Theoretical background

The essential criterion for defining a metaphor in this chapter is "cross domain mapping" (Steen, 2010, p. 49) or "semantic transfer" (Cameron, 2003, pp. 59–60). The present analysis classifies as metaphor any word or phrase from a formative source domain which transfers anything more than its literal concrete meaning to a different (often abstract) target domain (Schmitt, 2003).

In regards to its social role, the term metaphor will, in this article, be applied according to Weinrich's broader concept of metaphor (Weinrich, 1980). Weinrich's concept of the metaphor intersects with that of Lakoff and Johnson (1980), who agree with Weinrich that metaphor is a constant component of the collective memory and thus a structural element of social relationships. Furthermore Blumenberg (1960) and Lakoff and Johnson (1980)[1] claim that metaphors are neither arbitrary nor without effect, but rather give structure to social relationships and even function as "orientation for our *future* actions" (Lakoff & Johnson, 1999, p. 179; see also Koller, 2003, p. 115). The application of conceptual metaphor analysis and Lakoff and Johnson's theory of conceptual metaphor support the notion that conventional metaphors are used automatically, and non-deliberately (Steen, 2010, p. 43; Koller, 2003).

In contrast to this broad understanding of the prominent sociocultural role of metaphors, more recent studies in the field of systematic metaphor analysis reveal the context-specific *functional* content of metaphors (Schmitt, 2003). Focusing on the specific functionality of metaphors they also take into account the contextualization of their current use. To this end, Halliday's three meta-functions of language are usually quoted (see e.g. Cameron, 2003; Goatly, 1997; Herrmann, 2013; Koller 2003; Semino, 2008; Steen, 2010): Halliday (1973, 1978) differentiates between the interpersonal, the ideational, and the textual function. According to the interpersonal function of metaphors, a phrase can be understood as an interactive 'event', where "the speaker adopts for himself a particular speech role, and in doing so assigns to the listener a complementary role which he wishes him to adopt in his turn" (Halliday, 1994, p. 68). Thus, identities and relationships are created and negotiated.

The ideational function of language enables us to represent experiences as coming from a specific perspective, from which, in turn, reality is (re-)constructed. The textual function serves to make a text coherent. The present contribution is therefore mainly interested in the ideational and the interpersonal attributes of metaphors. This means that (metaphoric) texts contain "actualized meaning potential" (Halliday, 1978, p. 109), i.e. the possibility to fill gaps in a text. According to Koller (2003), this corresponds with Lakoff and Johnson's description of metaphors both highlighting certain meanings and masking others. During the process of mapping, only certain characteristics of the source domain are highlighted, whilst others remain hidden.

1. See Jäkel (1997, 1999) on Blumenberg as a predecessor of the Cognitive Theory of Metaphor.

In respect to the interpersonal level, the metaphor is a discourse component which transcends an individual instance of speech or text. For example, it can involve the context of different (academic) disciplines or institutions. However, in contrast to metaphors only used in public texts, those metaphors used in the communication between scientists, thus within the scientific community, tend to be technical terms which have become conventionalised in scientific communication. Some of them are background metaphors:[2] background metaphors are necessary professional, and thus irreplaceable, metaphors, ultimately added to the dictionary.

Such necessary background metaphors can be divided along the line between clarity versus richness. "Clarity" as a feature of scientific metaphors means exactness, at least in scientific writing for scientists (Gentner, 1982, pp. 124–125), which gives way to "richness", meaning the amount of content that is transferred from the source to the target domain. Necessary background metaphors are culturally significant and understood beyond the field of the scientific discipline. They are fundamental in providing the field with an overall intellectual and functional model or central scenario, which is often fictional. The TEXT metaphor in genetics is an example of such a necessary background metaphor. There are other necessary metaphors which do not count as background metaphors and which are technically very specific and limited. They do not abound in richness but are clear to the scientists in a specific discipline. Such metaphors are conventional for building a common language within a scientific field, but not necessarily in a more general audience's sense (e.g., Cameron, 2003; Low, 2008; Semino 2008). In bioscience journal articles, Giles (2008) found that such metaphors in the context of cells and genetics were *gene expression*, *colony* or *programming* which could be found in the respective scientific dictionaries as well. Here, I will use the term necessary metaphor only for those metaphors that are specific to the discipline. In contrast, I talk of (necessary) background metaphors when they additionally serve to organize the field.

The difference between necessary technical terms and background metaphors marks the differences in the metaphoric use between expert discourse among scientists and expert discourse going public in order to convince the audience. The metaphors differ as follows: (1) With the development of new technology experts develop a specific vocabulary involving metaphors that become technical terms in the specialist discourse. (2) Another set of repeatedly used metaphors develops when political institutions and stakeholders such as industry take a

2. The 'background metaphor' was introduced by Blumenberg (Blumenberg, 1998). This concept refers to those conventional metaphors which make up the fundamental ideas of a discipline and are essential to the development of theories.

position towards this new technology, promoting or rejecting it. (3) A third type of metaphors may be used when the expert discourse goes public about the new developments. These sets of metaphors can show overlaps.

In past decades, analysis of metaphors in the biosciences using different methods and approaches rendered extensive results. Hans Blumenberg (1960, 1983, 1998) was one of the earliest protagonists, presenting diachronic cultural studies of core metaphors and their broader cultural use in the fields in medicine and biology. As public texts of these fields show, the structural function and the pedagogical function of a text often go hand in hand to explain theories to lay audiences (Herrmann, 2013). Describing the use of metaphors in texts on ant colonies, Goatly found that the notion of "ants as an 'army'" help to organize the whole text (Goatly, 1997, p. 163).

Richness and even fiction are qualities normally found in literary texts. But for journalists working for quality media, though they might use metaphors frequently especially when writing on the sciences are bound to a neutral reporting tone in their texts. They need to keep a distanced and critical perspective, as the Press Code, preventing press from raising unfounded hopes in the public, binds them. This tends to result in a factual, clear tone in their articles. Thus, quality media usually keeps a journalist taboo on propagation of – in the respective country – contested technologies. Sometimes however, we also find richness and fiction in quality print media, as appears to have happened in the material studied here.

Editors, respecting the ethical rules for journalism including the taboo of promoting contested technology may decide to invite others, specifically marked as non-journalists (but experts). Such guest authors and interviewees speak about potential future possibilities of how, for instance, the world regarding reproduction could look like with the merging of reproductive and genetic technologies. Since such articles talk about possible, but as they say for legal reasons, currently non-existent (future) scenarios, an essential characteristic of these essays is that they inevitably contain scientific fiction. In contrast to the journalists, guest authors are freer in expression. These guest authors, identified as such, find themselves unbound from their scientific ethos and liberated from their usually strict way of straight technical writing; this may render them less responsible for proving their claims. In this non-disciplinary medium, when describing future scenarios, they are allowed to be tendentious: imagining the future from their optimistic viewpoint, they might omit potential obstacles or risks in the development and use of the technologies.

Purpose of the study

The here presented study showcases a detailed analysis of such an expert discourse going public about a new development, while embedding it and comparing it to the metaphor use within the expert discourse itself and to the non-expert public stakeholder discourse. In this vein on the following pages I analyze texts published in the public media in which their editors draw on experts as authors and interviewees to sketch the possibilities and future visions offered by reproductive technologies.

This contribution examines the extent to which articles on the subject of the specific field of reprogenetic technologies (i.e. the combination of genetic technology with in-vitro fertilization and cloning) use metaphors in both an educative sense and for other purposes such as convincing the readership.

The next section will explain the specificities of the analysis of expert interviews and essays in public media. Furthermore, it will introduce the method of analysis according to metaphor theory applied to these texts.

2. Methods

The first step in my analysis for this chapter was to concretely define a broad target domain to include reproductive technology on humans in combination with genetic technology and in-vitro fertilization, as well as human cloning. The terms “reproductive technology”, “procreation”, and “genetics” were also included. I conducted a broad, non-systematic accumulation of conventional background metaphors including examination of the use of metaphors in professional journals, dictionaries, and textbooks, as described below.

The texts chosen for this analysis were selected firstly through limiting the publication period to between 1995 and 2003.[3] This time period was defined in response to Graumann’s (2002) observation that the ethical debate about human bio-technology in reproduction, especially cloning, was initiated in Germany by the birth of the cloned sheep Dolly in 1997.

My corpus comprises texts from so-called quality print media, magazines and newspapers of high circulation, i.e. *Frankfurter Rundschau*, *Frankfurter Allgemeine Zeitung*, *Stern*, *Die Zeit* as well as *Süddeutsche Zeitung, Focus,* and *Der Spiegel* (Informationsgemeinschaft zur Verbreitung von Werbeträgern, 2000), and further from the best-selling magazines of popular sciences, such as *Geo* and *Spektrum*

3. The material used for this article, as well as parts of the analysis have been published in a different context (an analysis of the change of the notion of health with assisted reproductive technologies combining cell and genetic technologies) for the first time in Bock von Wülfingen (2007).

der Wissenschaften, as well as individual findings in the feminist journal *EMMA* and the philosophical journal *Ethica*. While the aim in forming this corpus was to carry out more extensive discourse analysis of the broader context, the corpus for the more detailed analysis of metaphors was then limited by selecting only articles which argued in favor of more liberal regulations of new reproductive technologies in Germany.

The selection process resulted in a final corpus of 35 articles. Only after this selection process did it emerge that all of these German articles were either interviews with or contributions by experts from the natural sciences and medicine mainly stemming from abroad. After what was said in the introduction about the difference of writing rules for journalists in quality media and the less strict rules for guest authors, it may not come to any surprise that these texts were rich in metaphors. These authors might be said to use fiction as a literary tool.

My methodology is based on systematic metaphor analysis (Schmitt, 2003), which links the insights of cognitive linguistics and conceptual metaphor theory (Lakoff & Johnson, 1980) to the systematic reconstruction of metaphoric patterns.

As said in the introduction, it is the ideational function of language that enables us to view and reconstruct text as belonging to a specific perspective. Furthermore, on the interpersonal level, the metaphor transcends an individual instance of text. It can for example span over different disciplines. In the type of texts I discuss in this chapter, which are mostly translations from English to German, there are additional factors, which make it nearly impossible to discern an individual author and thus an intended meaning by the use of a specific metaphor. In most of the cases I discuss, English-speaking experts are not only edited by journalists but also translated. Translating these German words back into English for the purpose of this publication shows a difference between the English and the German terminology that should be pointed out: Many German metaphors, for being centuries old terms, serve as technical terms, such as "Ei" (egg). Contrast this to English, where words are often Latinized (e.g. "ovum" as well as "intervention" or "manipulation" instead of "Eingriff") and seem more technical. So, where in German many metaphoric words used in this corpus seem automatically to embed reproductive issues and respective technologies into a pre-modern world of the farm, the corresponding English words do not.

The first reading of such metaphorical use could suggest that the respective authors intentionally seek to provide reproductive high-tech with normalcy by relating them to the harmless beauty of botany and gardening. This could give the appearance of metaphors chosen and used deliberately. The term "deliberate metaphor" is generally claimed to have been introduced by Goatly (1997). According to Steen (2010), deliberate metaphors are used to provoke a change of opinion or to motivate the audience to perceive a topic from a different perspective. However, in the texts discussed here, the gardening metaphors were, in most of the cases, not originally used by the natural scientists but by those who translated their texts and interviews; we can assume their intentions may not be the same as those of the scientists.

Additionally, as these terms are necessary metaphors in biology, it is even difficult to omit their use. So, instead of trying to claim deliberate metaphor use and find 'real' meaning and intention in the utilization of specific metaphors, the focus here is to recognize the functions of text in a larger institutionalized field (natural sciences and medicine).

3. Results: Metaphors on the threshold to a new era

As will be detailed in the following, the metaphorical world of the essays and interviews making up my corpus conveys a gripping narrative. To capture this narrative I propose an allegory that is suggested by my findings: To the degree laypeople approve of reproductive genetic technologies they will make their way from a DANGER-prone (3)[4] present in which we practice conventional conception without reprogenetic aid by taking a JOURNEY (4) to a better future, the latter represented by metaphors bundled under the notion of the COLONY (5) and enmeshed with the metaphoric field of VISION (6) of a desirable future. The journey culminates in humankind being able to MANAGE NATURE (7). To make reading easier, my numbering of the groups of metaphors corresponds to the story told through metaphoric use. Together these metaphor groupings transmit the fascination of the speakers with the possibilities of reproductive medicine in combination with genetics.

The allegory is of humankind that is in danger as long as it is still under the yoke of nature, but which is already on a journey to a prosperous colony with visions of a future in which it is able to itself manage nature. As later sections show, this allegory corresponds to a distinct central scenario (Koller, 2003) that runs through these texts. It portrays fundamental, liberating cultural values that have governed the development of natural sciences and technology for centuries. Already in its very beginning first enlightenment empiricists used a morally laden narrative of the journey with biblical connotations similar to what we find in the here presented corpus. Politicians preparing the public for the Human Genome Project build the connection between this long tradition of the journey metaphor and the recent

4. To ease reading, this overall journey from the primitive present times to a better future is in my representation indicated by an upward numbering of the metaphors. Metaphors in quotes that further describe the context are not numbered, but just quoted as usual.

scientific discourse going public on new and contested reprogenetic technologies. This central scenario underlines the motivation and function of the texts.

Subsection 3.1 first depicts the typical conventional metaphors found within the discourse of this discipline and that are typical for the context of reproduction and inheritance and of abundant use even within science. These are the metaphoric fields FRUIT (1) and TEXT (2), detailed in the following subsection. Then Subsections 3.2 and 3.3 present the metaphors apparently specific to the biomedical discourse on innovation found in the analyzed corpus. After that, Section 4, relates the results to the question of the educational function of metaphors and uses of the journey-allegory and metaphor in the history of natural science.

3.1 Conventional metaphors in reproductive genetics in popular media

As mentioned above, finding numerous background metaphors, in Weinrich's terms, stemming from the field of botany in the texts analyzed is commonplace within German discourse on reproduction and was to be expected.[5] These background metaphors furthermore are necessary metaphors (i.e. they are inconspicuous and difficult to replace, as no other acknowledged terms exist for the phenomenon). In the 35 articles analyzed, the metaphoric field of the FRUIT (1) appears to metaphorically describe the embryo or fetus: for example in terms of "chances of **implantation** of a selected embryo" (1.1), "**implanting** the **fruit**" (1.2), "**implanting** into the uterus" (1.3), "**fruit** water" (amniotic fluid, 1.4), "**planting forth**" ("Fortpflanzung": meaning reproduction or generation, 1.5), "impregnation" ("**Befruchtung**", 1.6), "hyper-intelligent **offspring**" ("Sprössling", 1.7), up to the "**germline**" (1.8), and "family **trees**" (1.9). Terms such as "to **stem** from" (1.10), "**stem cells**" (1.11), and "**cultivating** stem cells" (1.12) also come from the field of botany.

TEXT AND WRITING (2) is another source domain of many metaphors in the articles studied: be it an actual book or a text in computerized form. Both the metaphors of the 'genome as book' and those of the DNA as a code taken from cybernetics can be taken for background or even necessary metaphors. The use of metaphors stemming from printed books is clearly dominant in the articles. Examples of metaphors closely associated with printed text which were used in the corpus include the "**write error**" ("Schreibfehler", 2.1) or "**letters**" (of "genetic material", 2.2.); that we are still working on "**deciphering** the human genome" (2.3)

5. Where the English translation differs much from the botany-related German notion, I use a direct translation to show the botanical meaning. Where there is no way of directly translating, I include the German term in brackets.

whilst the "**syntax and grammar** are yet largely unknown" (2.4), which would demand "ten thousand RNA-**transcripts**" (2.5).

These findings are in accordance with Christina Brandt's critical analysis of Lily Kays' theory. In Kay's examination of references to writing and codes in genetics since the 1950s, she concentrates on information sciences (Kay, 2000), while Brandt views the popularization of the writing metaphor as not based upon informatization (referring to Schrödinger, 1992), but in an "experimentalization of the genetic code" (Brandt, 2004, p. 15) referring to Crick (1958). This discussion will play a decisive role later on in my discussion.

Below I will explore metaphors which appear in various of the articles analyzed and which stem from specific conventional source domains that here form background metaphors (as do some of those already mentioned above), but which furthermore seem to be specific to particular text types and the historical situation of reproductive genetics which will be discussed later.

Conventional metaphors can be located on a space/time axis – ranging from an uncontrolled nature of the present to a managed and controlled nature in the future. As said before, to ease reading, this overall journey from the primitive present to a better future is in my representation indicated by an upward numbering of the metaphors. This axis is limited by metaphors related to the uncontrollable and DANGER (3), such as for instance "**playing** the genomic **dice**" (3.1), "**playing the lottery**" (3.2), ibid., or the "**randomness** of nature" (3.3). At the other extreme of this axis are very practical metaphors that signal success in MANAGING NATURE (7) such as "having a **firm grasp** on" (7.1), directly translated as "to take a hand in" ("Eingreifen"), and "to **control** the genetic **equipment**" (7.2). This contrast and the role of technology as the solution are specified in more detail in the following subsections.

3.2 From dangerous random procreation without technology to new reprogenetic technology use

In most of the texts analyzed, metaphors relating to nature that is *not* technologically managed tend to link this situation to risk and DANGEROUS ARBITRARINESS (3). Thus it is deemed a "**nightmare**" (3.4) to have a terminally ill child; being in love or having sexual feelings are described as "a **thunderstorm** of the nerves" ("Nervengewitter", 3.5) and it is worrisome that we "can't control what happens during growth" (Wilmut, 1997, p. 220). The arbitrariness of Do-It-Yourself-procreation is described by such imagery as the "unplanned meeting of sperm and egg" (Stock, 2000a, p. 192), "procreation managed by **casting** the genomic **dice**" (3.6), "**playing the lottery**" (3.7) or "**throwing the** genomic **dice**" (3.8), where one is subject to the "**randomness** of nature" (Silver, 2000, p. 147) or even to the "**dice playing** nature" (3.9). So, whenever DIY-conception is described the conceptual metaphor realized by these metaphorical expressions is UNMANAGED CONCEPTION IS A GAME OF CHANCE. Together with the source domain DANGER, insinuated by "**nightmare**" (3.4) and "**thunderstorm**" (3.5), the metaphors portray DIY-conception as problematic and scary. While the above metaphors describe the phase before we even knew of the possibility to combine reproduction and genetic biotechnology, other metaphors are employed to describe the phase where we decide to use them. The decision-making phase as to whether or not to combine new genetic and reproductive technologies (for example whether or not preimplantation genetic diagnosis or genetic therapy should become standardized or whether cloning should be applied in reproduction) is described in the articles as an insecure but promising JOURNEY (4) across a certain space, as a "parting of the **ways** of evolution" (4.1) with "glamorous **prospects**" (6.1).

Metaphors relating to a "**turning point**" (4.2) from technologically unmanaged reproduction to the use of reproductive genetics are also often used in the articles to describe this decision-making phase as "marking a **crossover**" ("Übergang markieren", 4.3) into a different world or even to a "revolution" (Reich, 2000, p. 204; Stock, 2000b, p. 125). The metaphors suggest a technology-euphoric utopia, describing the beginning of a journey into a new world, comparable only to the past transition from medieval ages into modernity. The new science of reproductive genetics is viewed as a *path* into this new world, which we will have to decide upon. The movement within a temporal space is often mentioned. This includes references to the 'future path', such as the "**path** of life" (4.4), "life **track**" ("Lebenslauf", 4.5) or "a small **step**" into the future (4.6). The irrevocability of decisions is expressed in such metaphors as "we are at the parting of the **ways** of evolution" (4.1), the "**path** into the future" (4.7), to "**tread** into unknown waters" (4.8), "to measure this **journey**" ("diese Reise durchmessen", 4.9) or "inaccessible **destination**" (4.10). There appears to be a non-contradictory association with those pioneers connected with other metaphors from the field of the historical COLONIES, who first enter new paths to claim wild and unfamiliar territories. Thus US-Americans are perceived as a "**pioneer people**" (5.1) in terms of their use of cloning and other new reproductive and genetic technologies. On the other hand, we also find the warning that such a "disputable **pioneer activity**" (5.2) would happen outside of public control if cloning were not legalized.

Many articles relate developments in the field of pharmaco-genetics to what we can call the riches of the COLONIES (5): to the exploitation of promising resources in mining, saying that "scientists struck a **gold vein**" (5.3). Since gold was mainly salvaged in the colonies, this description of genetic 'discoveries' belongs to the same field of imagery as the "**pioneer activity**" ("Pioniertat", 5.4).

The evaluation of genetic possibilities is accordingly captured by the metaphor of the "**exploitation** of the human genome" (5.5).

The examples found in the corpus refer to space less in the sense of an area or vessel, but more as a temporal space. Spatial language is not found, but bounded-space, i.e. container language, appears as well as graspable objects such as treasures. In the texts analyzed, these non-spatial metaphors still evoke the idea of travel from a more primitive to a more developed state, from the epoch when we moved slowly and inconveniently through phylogenetic phases representing our evolutionary history, paralleled by our ontogeny through hazardous stages of life, to the future where reproductive and genetic technologies will move us forward much faster and safer. Thus on the one hand there is the 'progressive' break with a human epoch which did not widely employ new reproductive or genetic technologies, which is viewed as a "weirdly primitive epoch in which people only live 70 to 80 years to then die of horrible diseases" (Stock, 2000a, p. 192). On the other hand, humanity is seen to be "**leaving** its childhood **behind**" (4.11).

Metaphors from the field of vision such as "**prospects**" (6.1) into the "distant future" (Green, 1999, p. 65) are often used in the texts to express a futuristic exploitation of possibilities, of overcoming temporal or spatial distances. The sentence "if we **look** a hundred or a thousand years into the future – a mere instant in evolutionary terms – we are sure to have adopted functional cooperation with such appliances" (6.2) illustrates, in its grasp of time, just such an accomplishment. However, "we do [actually] not need to **look** that far ahead" (6.3).

This field of metaphors combines a notion of the sciences as a path through space with science as a means to overcome physical hindrances. To apply the techniques which science and technology offer will lead us towards a society in which nature is no longer dangerous but serves society. Nature will be under control and metaphors of handcraft signal that this is in fact an easy task, as we can see in the following subsection.

3.3 A firm grasp on the future: Reproductive technology means to manage nature

Although genetic material can only be handled by using chemical processes and the machines that have been created for these processes, the texts often refer to the genome as 'within reach' ('zum Greifen nah') and as apparently able to be shaped by human hands within this metaphoric field of MANAGING NATURE (7). Thus the opportunity of "taking a hand on the human genetic make-up are almost endless" ("**Eingriffsmöglichkeiten** ins menschliche Erbgut nahezu grenzenlos", 7.3). The metaphor "**intervention**" ("Eingriff", 7.4) is also frequently used to describe changes to genetic material, the "**germline**" (1.8) or the "hereditary estate"

(“Erbmasse”: Stock, 1998). Such “genetic **manipulation**” („Genmanipulation“, 7.5); germ line **manipulation** („Keimbahnmanipulation“, 7.6), “improvement **manipulation**” (“Verbesserungsmanipulation”, 7.7), or “**handling**” (7.8), which “**produce**[s] far-reaching changes in our biology” (“tief greifend”, 7.9), a “true **command** of the technique” (7.10) is as important as a “responsible **handling** of these new forces” (7.11).

Instead of procreation consisting of the “amalgamation of egg and sperm” (“Verschmelzung”: Katzorke, 2003, p. 149), which is like “a **lottery game** […] for the **production** of offspring” (3.10, 7.12), soon “conception in the sense of **producing** a fertilized human egg cell” (7.13) could become the desirable norm; that is to say we could “**produce** children” (7.14) and “**design** the baby” (7.15) in the process. If the qualities of the child can be “**designed**” (7.16), then “**fitting** […] the genomes” (7.17) of the two parents to one another can also be controlled, to conceive healthier and happier children. An industry offering these new reproductive and genetic technologies, including cloning, could bear the fictional acronym “IGET” (Hamer, 2002, p. 24). Instead of fertilizing an egg cell, one could carry out fertilization after “**activating** the egg cell” (7.18), i.e. through cloning, by which “genetic **copies** of humans can be generated” (7.19). The embryo is associated in some utopic fictional parts of articles with useful household appliances that make our lives easier. Also the embryo is associated with food, where we find it ‘normal’ to have a choice, provoking comments that “the genetic **equipment** of the future child is designed and ordered just like the kitchen for our new home” (7.20), or that we could in future choose our forms of reproduction as from a “**menu**” (7.21) in the “reproduction **restaurant**” (7.22). Being both direct and persuasive these last three metaphors are some of the rare deliberate metaphors in the analyzed corpus.

This way of “**producing** offspring” (7.23) would allow “**control** [over] the genetic **equipment**” (7.24). An embryo check in-vitro would lower the rate of malformation due to the “background risks, the parents bring with them” (Diedrich, 2003, p. 42). “Any hereditary disease” (Katzorke, 2003, p. 149), “grave genetic diseases for which we don’t have therapy and which end with an early death” (Rosenthal, 2001, p. 92) or phenomena such as morbus down (Djerassi, 2002, p. 76; also termed down-syndrome) could be prevented “by a routine pre-implantation embryo check” (Katzorke, 2003, p. 149), where parents can choose the embryo without the “sick version of the gene” (Rosenthal, 2001, p. 92) as “only one in five embryos is genetically intact “(Katzorke, 2003, p. 149). And if after a test – at the latest during the “embryo **check**” (7.25) – the “quality of the **product** didn’t satisfy the quality requirements” (7.26), one could “genetically correct handicaps” (Silver, 1998, p. 145) by means of ‘genetic therapies’. Cloning and gene therapy could prevent the transmission of “**risk** genes” (3.11), so that these “could finally be eliminated from the **family tree**” (ibid.: 65, 1.13). This doesn’t only concern illnesses such as Huntington-Chorea or Tay-Sachs, but could also refer to "undesired ways of behavior" (Hamer, 2002, p. 26) as well as "all classical forms of psychosis" (Green, 1999, p. 28) or "schizophrenia" (ibid.). In those cases where illnesses go back to complicate interactions between genetic and environmental factors, at least the genetic predispositions for "syndromes such as manic depressions, obsessive-compulsive disorders and hyperactivity" (Hamer, 2002, p. 28) could be eliminated.

This "**manipulation** of human biology" (7.27) could, however, not only be used for 'corrections', but also for "genetic **improvements**" (7.28). If we wish to "**improve** genes" (7.29) we might as well "include genetic **controls**, which allow to **switch off** the genes" (7.30) when those new genes fail to satisfy the quality standards. It was also important to affirm that legalization in democratic high-tech countries would prevent "germline **manipulations** […] **in the hands** of clichéd crazy scientists who want to create a new super-race" (7.31). Accordingly, "**manipulations** which not only affect our physiology, but also our emotional and spiritual world" (7.32) would ultimately "**recreate** our life completely" (7.33).

The analysis reproduced in this subsection has shown that the history of emancipation through science, wrapped in metaphors pertinent to the metaphoric field of the JOURNEY (4), enmeshed with COLONY (5) and VISION (6), constitutes the scaffold of the argumentation in favour of the combined use of reproductive and genetic technologies. In the following discussion, this scaffolding by the quoted scientists when they address the public will be further explored.

3.4 Discussion: The journey in history of science and technology

Is the JOURNEY (4) an exceptional metaphoric field in the recent life sciences communication to the public, and/or is it specific to discussions of reproduction and genetics? Historically, in earlier centuries, especially when the concepts to be communicated were publicly contested, JOURNEY (4) was a popular literary theme used for 'public communication of science'. Furthermore, the texts reflect a contrast between allusions to enlightenment values, contained in scenarios which point out our obligations and responsibilities, and more pre-modern notions of a rational individual who has emancipated herself from (her own) nature through empirical insights into the workings of nature itself. In the early modern era the scientific project – liberalization through reason – was often described as a path through space. As Hobbes explained "[r]eason is the pace; increase of science the way; and the benefit of mankind the end" (Hobbes, 1886, p. 30). Descartes describes colleagues who in his eyes work with the wrong methodology as "travelers who leave the main path to take a shortcut, only to find themselves lost amongst briars and precipices" (Descartes, 1984, p. 401).

One of the earliest and noted forerunners in the dawn of modern science is Francis Bacon, who in archetypical ways used JOURNEY (4), COLONY (5) and VISION (6) to campaign for science and a scientific methodology as such. It is with this political philosopher engaged in the study of nature at the beginning of the 17th century in particular, that the technological utopia and the euphoria regarding the projects of colonization are used metaphorically when discussing scientific and political innovations.

Bacon's perspective on the project of natural science differs in its epistemological approach from that of other enlightenment researchers. According to those others, nature, when experienced in a physical, empirical way, can only be known within the limits of perception and reflection, as indicates the English empiricism of Locke (1979) or Hume (2000). Otherwise the idea was implied that the reflecting intellect and nature are inseparable from one another (as with Spinoza, 1986). For Bacon, instead, 'real' knowledge should be possible like a mirror to the world, if only humans could rid themselves of their mistaken consciousness, namely their prejudices (Bacon, 2000).[6] As Bloch claimed "[t]his mistaken consciousness has never again been discussed with the same detail or passion in bourgeois philosophy" (Bloch, 1977, p. 254; translation B.v.W.).

The means of illustrating the human being captivated in nature's arbitrariness, putting humans in DANGER (3), contrasted with the dawning liberation through genetic technology in the metaphoric use described above, show similarities to Bacon's announcement and propagation of a new era of research into nature with the empirical sciences. These commonalities are mainly marked through metaphors of the JOURNEY (4) or concretely the PATH (4.4, 4.7) to scientific innovation and its recognition and application by society. Bacon, like other utopian authors of his time inspired by Columbus' discovery of the 'New World', aimed to discover an 'intellectual world', an analogy reflected in the metaphoric field of the COLONY (5). This would allow the natural sciences to offer humans the same material salvation as the Kingdom of God at the end of all times (Tarnas, 2001, p. 242).

Bacon draws this analogy between the discovery of the colony and achievements of especially (bio-)medical sciences in paradigmatic fashion in two books: The title page of the first edition of Bacon's explanations on this new form of sciences, the *Novum Organum* of 1620, bears a frontispiece showing a ship sailing between the Pillars of Hercules (Gibraltar & Helferich, 2001, p. 152). If the path into this new intellectual world is both difficult and isolating, the journey ultimately

6. If nature was imperceptible, this was due to "the way which is now in use. They [authors who assume nature to be imperceptible] thereupon proceed to destroy the authority of sense and intellect; but we devise and provide assistance to them" (Bacon, 2000, p. XXXVIII, 40).

promises the discovery of a kingdom of paradisiacal democratic conditions, since this world will be governed by scientists of an open and unprejudiced mind.

Another one of Bacon's works, *Nova Atlantis* of 1627 (Bacon, 1993, p. 111, 118), describes such an ideal society living on an isolated island off the coast of America. The narrator and a group of men from Europe on a ship reach this island. The journey had been hard, but the group is finally welcomed on the island. The democratic and at the same time Christian island state, Bensalem, is governed by natural scientists (the Society of Salomon's House, Bacon, 1993). The scientific innovations of the Society of Salomon's House care for the physical intactness of everyone living on the Island of Nova Atlantis (Bensalem): various foods are in abundance, while the Society studies and produces medicinal fruits and substances, not only breeds but also *creates* formerly unknown animals, and generates life-prolonging products (Bacon, 1993, pp. 129–131). This society achieved freedom for itself from the grip of nature and thus to MANAGE NATURE (7).

Within this allegory of Nova Atlantis, another shorter allegory is contained – the discovery of the bible as instruction for the PATH (4.4, 4.7) to knowledge on the one hand and the result of the search for knowledge on the other. The narrative depicts the origin of Bensalem (Nova Atlantis) as occurring one night when the people of the island saw a shining cross over the sea and took their boats out. When none of the boats could approach the cross, only the wise man of the island was 'unbound' (Bacon, 1993, p. 112) after he had said a prayer to God about his aims in the laws of nature. Once the wise man reached the cross, it turned into a chest containing the Old and the New Testament as well as a letter of the apostle Bartholomew who explained that he had trusted these works to the floods (ibid.).[7]

This allegory, like the scenarios introduced above, all suggest that nature itself (also in the form of evolution) provides us with the means and thus the duty to take evolution into our own hands. For Bacon, the rewarding exploration of nature through the sciences (see COLONY, 5) is the PATH (2.2, 2.7) to the knowledge of God, led by God Himself, turning the scientist into a priest. This corresponds with Bacon's deistic background, believing that whilst God created the world, He no longer interferes in it, leaving humans to their own devices (Tarnas, 2001, p. 342). This concept treats God as equal with nature. The perception of nature, the 'victory' over nature by following its laws to improve the well-being of humans, is thus a continuation of God's work, which is inscribed into natural laws (Helferich, 2001, p. 155). Since in this concept God is viewed as the initiator, who can now only be found in nature itself, it can be used in evolutionary biology without

7. The author of "The selfish gene", Richard Dawkins, describes the inherited genetic material as a "family bible" in another of his works (Dawkins, 1995, p. 39).

reference to any God.[8] Nature now stands separately, allowing humans to seek knowledge and to procreate for their own well-being.

The book and TEXT metaphors (2) mentioned above present similarly religious associations that are discussed further below. The logic of the analyzed texts follows this picture: for the next step is to decide to combine genetic and reproductive technologies and to realize the benefits of human intervention into evolution, which are represented mainly by metaphors of handcraft. We may interpret Bacon's allegoric oeuvre as a mere strategical pamphlet to make society and the church more comfortable with the sciences. Nevertheless, beyond this function, considering Bacon's Christian background, we may as well assume that the allegory of the JOURNEY (4) and COLONY (5), enmeshed with VISION (6) and MANAGING NATURE (7) is for Bacon his ethical guiding principle. This ambiguity between educative manipulation and generative guiding principle is an ambivalence in the use of metaphors as well as in the interpretation of their function, which Bacon's JOURNEY metaphors share with their use today, as I will discuss in more detail below.

As already shown we can discern conventional metaphors of general use in biology, such as those from the fields of FRUIT (1) and TEXT (2), from others which are specific to what we could call scientific fiction aimed at the broader public. Implicitly the authors enthusiastically follow the Baconian journey allegory and thereby carry forward a near spiritual, morally laden, subtext arguing in favour of the combination of genetic and reproductive technologies. In fact, the metaphors used to arrive at an appealing and convincing narrative observed in the analyzed texts date back to Bacon's times: the human is confronted at the crossroads (4.1, 4.2, 4.3) of evolution with a far reaching decision to make: to follow the better path to put human evolution in the hands of humans applying laboratory techniques or to follow the traditional path of DIY reproduction. This challenge can however, if humankind makes the right decision, lead to a rewarding future (4, 5, 6, 7).

Obviously, the function of the JOURNEY (4) metaphor in the above-analyzed texts is not pedagogical, in that this metaphor is not applied to the technology itself in order to understand the exact working of an otherwise abstract and sensually difficult to perceive phenomenon (Jäkel, 2002). Instead, the metaphoric field of the JOURNEY (4) portrays the use of technology as an emancipatory process of humankind, thereby promoting the use of the technology, and along the way fulfils the textual function of keeping the text together, serving as a storyline. Through its specific history the metaphoric field of the JOURNEY (4), and concretely all the metaphors related to the PATH to tread on (4.1, 4.4, 4.6, 4.7, 4.8),

8. The changes in the concept of God as an omniscient, "Leviathan" outside of nature in early natural philosophy into a force working between, and meanwhile even within, molecules such as the Laplace or the Maxwell Demon is described by Evelyn Fox in *Refiguring Life*, Keller (1995).

additionally carries a religious undertone (Bacon, 1993; Jäkel, 2002) relating to the Old Testament. The result is a clear moral imperative: LEADING A MORAL LIFE IS MAKING A JOURNEY ON GOD'S WAY" (Jäkel, 2002, p. 25): As a general literary theme we find the source-path-goal scheme in many cultures, independent of religion (Lakoff & Johnson, 1980, pp. 88ff.). In the religious context however, it has this specific moral connotation (Charteris-Black, 2004, p. 208).

Already the exodus of the people of Israel out of Egypt contains an allegory of human emancipation: a mental progress from polytheism to the one God of Israel (Assmann, 1998). More often however, according to Jäkel, over half of the cases of the journey metaphor in the Old Testament "are concerned with worldly wisdom" (Jäkel, 2002, p. 25), located in the two books of Psalms and Proverbs.

The concept of nature as TEXT (2), again, is based on a long tradition of the metaphoric use of the 'Book of Nature'. This can be seen in Schrödinger's *What is Life?* as well as in Francis Bacon's utopian work *Nova Atlantis*. The writing metaphor for DNA was first introduced as a theory constitutive resource in reciprocal exchanges among scientists, allowing experimental classifications until it finally achieved ontological status (Brandt, 2004, pp. 257ff.; see also Chargaff, 1970) and became a conventional metaphor for which no other term was available. As Schrödinger stated: "the great revelation of quantum theory was that features of discreteness were discovered in the *Book of Nature*, in a context in which anything other than continuity seemed to be absurd according to the views held up until that time" (Schrödinger, 1992, p. 48; emphasis B.v.W.).

Blumenberg describes this very consistency as one of the qualities of the Book of Nature. There is the idea that nature was "a whole from a single cast" (Blumenberg, 1983, p. 18; translation B.v.W.), limited, and thus easy to MANAGE NATURE (7), and in itself contained and containing a "temptation to totality" (ibid.; translation B.v.W.). The Book of Nature metaphor also points to a paradox: "Nature was a book, but one written in hieroglyphs, in ciphers, in mathematical formulas – the paradox of a book which refuses to be read" (ibid.; translation B.v.W.). Nature is thus not simply self-evident, but only able to be experienced through man-made rules, which will, by definition, also become natural laws.

As with Francis Bacon the laws of nature themselves have been viewed since the end of the Renaissance as the will of God. In these readings, the Book of God (i.e. the Bible) and the Book of Nature are synonymous (Curtius, 1948). The media texts from my corpus, which I analyzed above, often present the point of view that cloning or preparing human DNA for different processes are acts of evolution or of nature when 'We' become creators (7, especially 7.14–7.17, 7.19–7.30, 7.32–7.33).[9] 'Our' actions are thus legitimate through being a continuation of God's work.

Meanwhile, the scenarios of new genetic and reproductive technologies form a dialectical relationship with the scenarios of liberation and determinism. These latter scenarios envisage that technologies should be made available, because they liberate us from the limitations of (our own) nature (DANGER, 3, versus MANAGING FUTURE, 7). These scenarios can only be understood through the framework of some 'dogmatic gene', a deterministic concept which inevitably leads to a dreadful disease if neither society nor reproductive biology or genetics can offer a solution (see subsection 3.3).

In a similar sense, the TEXT metaphor in genetics (2.1, 2.2, 2.3, 2.5), used to explain, for example, the predisposition to diseases in our children, is linked to the 'inscriptions' in our genetic material. Note, however, that 'literacy' (2.4) can prevent such problems in the reproductive process, if we only change the 'text'.

The main epistemological advantage of the TEXT metaphor (2) lies in the fact that it both represents flexibility (interchangeability of letters) and continuity (inheritability). The 'dogmatic' interpretation of the TEXT metaphor, instead, only emphasizes the aspect of continuity. Humans are thus fatefully chained to their genes, which determine their lives. However, humankind is seen as being on a JOURNEY (4), which will, if the right PATH is chosen, lead to their final liberation. The powerful reference to the metaphor of space (Brown, 1998, 2003) as something which needs to be crossed and transcended (4, especially 4.3, 4.7, 4.11), and which is tightly linked to time metaphorically understood as space (see especially 4.4–4.7), alludes to the *spatial turn* of the end of the 1990s, when not only time but space came into the focus of socio-cultural analysis. The metaphoric domain of text and book refers both to eternity and stability as well as to universalization and expansion (Anderson, 2005). The expanding space is simultaneously 'internalized' because genetic material is perceived as a temporal molecule which needs to be 'exploited', changed, stored, or saved (see COLONY, 5, especially 5.3–5.5).

Similar to the metaphoric field of the COLONY (5) reported here, Nerlich, Dingwall and Clarke (2002) found in discourse on genetic innovation in the United States, the reference to US American pioneer settlers, transgressing space risking their lives, always being faithful in God. The authors showed that this amalgamation of 'pioneer science', Christian belief and American History was constructed during the time of the Human Genome Project (at the end of the

9. See e.g. Stock (1998): "We begin to change the building plans of creation, even our own. […] The truth is […], that we already hold the power in our hands." Stock (2000b): "Because our cultural evolution now gives us the power to change our biology" (Stock, 1998, p. 125; translation B.v.W.).

1990s) in an interaction between politics, biomedicine and media. This occurred especially in the speeches on genomics of U.S. President at the time, Bill Clinton, in which "an inspirational tone and a counter-theology" combined (ibid.: 453). Clinton's speeches were evidently intended to counteract the threat that pro-life religious citizens perceived in the Human Genome Project.

Such religious undertones are rather alien to the German scientists' public portrayal of technological advancements in genomics and the reproductive sciences. The well-informed and often critical German public would be more likely to accept a less glossy, prophetic, and pioneer-related discourse. This was true when the so-called new reproductive technologies were reported in earlier years.

However, the JOURNEY metaphor (4) might still be successful in this foreign context. Recall that metaphors are frequently found in fiction (cf. Jakobson & Halle, 1956; Lodge, 1977; Semino & Steen, 2008). And I argued above that the popularized texts describing reproductive technologies that we are dealing with here have many of the characteristics of fiction. Metaphor used in fiction, contrasted with its use in science writing, is rather broad and opens up imaginative space, just as do metaphors in lyrics. When metaphors such as JOURNEY support broader narratives, they enliven the texts, making them more provocative and capable of triggering public discussion of relevant medical topics that have important political implications. They may appeal to the (religious) explorer in the readership.

As said earlier, a metaphoric phrase can function interpersonally and be understood as an interactive 'event', where "the speaker adopts for himself a particular speech role, and in doing so assigns to the listener a complementary role which he wishes him to adopt in his turn" (Halliday, 1994, p. 68). This, in Goatly's terms means "acting on others" (Goatly, 1997, p. 302) who (in these texts) are meant to be taken on that journey into a better human future, enabling them to view the issues at stake from a new perspective, sharing with the scientists the excitement about our future possibilities.

Although this suggests a deliberate use of metaphors following the specific aim to tell a convincing story, there are several doubts about such deliberate use: First, most authors will be unaware of the metaphoric status of the terms they use (apart from "**menu**", 7.21, in the "reproduction **restaurant**", 7.22). Second, when we speak of 'acting on others', the question that has already been raised in the introduction is who the actor in the cases presented here is. Is it the Anglo-Saxon scientist in most cases, with his specific interests? Or is it the German journalists and editors involved in each article and interview, who translate the text and choose specific terms over others – again with different interests in mind? A third doubt arises from our not knowing if educators are choosing the metaphors according to what seems best pedagogically, or if scientists are choosing them based on their firm conviction: the JOURNEY to the betterment of society may indeed be the guiding principle of scientists' work, just as Bacon may have seen it over four centuries ago.

Literature corpus of the analysis of metaphors

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Appendix. List of metaphors

(1) FRUIT

1.1 "chances of **implantation** of a selected embryo": Diedrich 2003: 42
1.2 "**implanting** the **fruit**": Reich 2000: 206
1.3 "**implanting** into the uterus": Wilmut 1997: 220
1.4 "**fruit** water" (amniotic fluid): Katzorke 2003: 149, Djerassi 2000: 212
1.5 "**planting forth**" ("Fortpflanzung", meaning reproduction or generation: Hughes 2000, Katzorke 2003: 149, Reich 2000: 204, 206, Silver 1998: 145, Stock 1998, Stock 2000a: 192)
1.6 "impregnation" ("**Befruchtung**"): Antinori 2001: 208, Baker 1999: 163, Diedrich 2003: 42, etc.)
1.7 "hyper-intelligent **offspring**" ("Sprössling"): Hughes 2000
1.8 "**germline**": Hughes 2000, Silver 2000: 146, Stock 2000a: 190, 191, 192; Stock 2000b: 123, 125
1.9 "family **trees**": Green 1999: 65
1.10 "To **stem** from": Solter 2002: 23
1.11 "**stem** cells": Rosenthal 2001: 92, Solter 2002: 23
1.12 "**cultivating** stem cells": Solter 2002: 23
1.13 "**family tree**": Green 1999

(2) TEXT AND WRITING

2.1 "**write error**" ("Schreibfehler"): Hughes 2000
2.2 "**letters**" (of "genetic material"): ibid.
2.3 "**deciphering** the human genome": Rosenthal 2001: 84
2.4 "**syntax and grammar** are yet largely unknown": ibid.
2.5 "ten thousand RNA-**transcripts**": Rosenthal 2001: 85

(3) DANGEROUS ARBITRARINESS

3.1 "**playing** the genomic **dice**": Reich 2000: 206
3.2 "**playing the lottery**": ibid.

3.3 “**randomness** of nature”: Silver 2000: 147
3.4 “**nightmare**”: Hughes 2000
3.5 “a **thunderstorm** of the nerves” (“Nervengewitter”): Reich 2000: 204
3.6 “procreation managed by **casting** the genomic **dice**”: Reich 2000: 206
3.7 “**playing the lottery**”: ibid.
3.8 “**throwing the** genomic dice”: ibid.
3.9 “**dice playing** nature”: Djerassi 1999: 51
3.10 “a **lottery game** […] for the production of offspring”: Reich 2000: 206
3.11 “risk genes”: Green 1999: 64

(4) JOURNEY
4.1 “parting of the **ways**”: Stock 2000a: 190
4.2 “**turning point**”: Silver 1998: 144
4.3 “marking a **crossover**” (“Übergang markieren”): Reich 2000: 206
4.4 “**path** of life”: Silver 2000: 147
4.5 “life **track**” (“Lebenslauf”): Hamer 2002: 24
4.6 “a small **step**”: Silver 2000: 146
4.7 “**path** into the future”: Silver 1998: 145
4.8 “**tread** into unknown waters”: Stock 2000a: 191
4.9 “to measure this **journey**” (“diese Reise durchmessen”): Reich 2000: 206
4.10 “inaccessible **destination**”: Green 1999: 64
4.11 “**leaving** its childhood **behind**”: Stock 2000a: 192

(5) COLONY
5.1 “**pioneer people**”: Silver 1998: 145
5.2 “disputable **pioneer activity**”: Green 1999: 62
5.3 “scientists struck a **gold vein**”: Hamer 2002: 26
5.4 “**pioneer activity**” (“Pioniertat”): Green 1999: 62
5.5 “**exploitation** of the human genome”: Rosenthal 2001: 85

(6) VISION
6.1 “glamorous **prospects**”**:** Silver 2000: 146, Green 1999: 65
6.2 “if we **look** a hundred or a thousand years into the future – a mere instant in evolutionary terms – we are sure to have adopted functional cooperation with such appliances”: Stock 2000b: 125
6.3 “we do [actually] not need to **look** that far ahead”: Stock 2000b: 123

(7) MANAGING NATURE
7.1 “having a **firm grasp on**”, directly translated as “to take a hand in” (“Eingreifen”): Hamer 2002: 26; Silver 2000: 146, 147; Stock 1998; Stock 2000a: 190, 192 etc.
7.2 “to **control** the genetic equipment”: Silver 1998: 144
7.3 “taking **a hand on** the human genetic make-up are almost limitless” (“Eingriffsmöglichkeiten ins menschliche Erbgut nahezu grenzenlos”: Silver 2000: 147
7.4 “**intervention**” (“Eingriff”): Silver 2000: 147, Stock 1998, Stock 2000a: 190,192; Stock 2000b: 123 7.5 “genetic **manipulation**” (“Genmanipulation”): Silver 1998: 142, 145; Stock 2000c: 125)
7.6 “germ line **manipulation**” (“Keimbahnmanipulation”): Silver 2000: 147; Stock 2000a: 191
7.7 “improvement **manipulation**” (“Verbesserungsmanipulation”): Silver 2000: 147

7.8 "**handling**": Stock 1998, Stock 2000b: 125
7.9 "**produce**[s] far-reaching changes in our biology" ("tief greifend"): Stock 2000b: 125
7.10 "true **command** of the technique": Solter 2002: 23
7.11 "responsible **handling** of these new forces": Stock 1998
7.12 "a lottery game […] for the **production** of offspring": Reich 2000: 206
7.13 "conception in the sense of **producing** a fertilized human egg cell": Reich 2000: 205
7.14 "**produce** children": Green 1999: 63
7.15 "**design** the baby": Hamer 2002: 24
7.16 "**designed**": Reich 2000,206
7.17 "**fitting** […] the genomes": ibid.
7.18 "**activating** the egg cell": Solter 2002: 23
7.19 "genetic **copies** of humans can be generated": Wilmut 1997: 220
7.20 "the genetic **equipment** of the future child is **designed** and **ordered** just like the kitchen for our new home": Reich 2000: 206
7.21 "**menu**": Baker 1999: 163
7.22 "reproduction **restaurant**" (ibid)
7.23 "**producing** offspring": Silver 1998: 145
7.24 "**control** [over] the genetic **equipment**": Silver 1998: 124
7.25 "embryo **check**": Katzorke 2003: 149
7.26 "quality of the **product** didn't satisfy the quality requirements": Reich 2000: 204
7.27 "**manipulation** of human biology": Silver 2000: 147
7.28 "genetic **improvements**": Silver 2000: 147
7.29 "**improve** genes": Stock 2000b: 124
7.30 "include genetic **controls**, which allow to **switch off** the genes": ibid.
7.31 "germline **manipulations** […] **in the hands** of clichéd crazy scientists who want to create a new super-race": Stock 2000a: 190
7.32 "**manipulations** which not only affect our physiology, but also our emotional and spiritual world": Stock 2000b: 125
7.33 "**recreate** our life completely": ibid.

CHAPTER 5

To be or not to be: Reconsidering the metaphors of apoptosis in press popularisation articles

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This chapter examines the metaphorical expressions used to explain apoptosis in press popularisations. The study was performed on a bilingual English-Spanish subset of 58 texts on apoptosis identified from a corpus of 300 cancer articles published in *The Guardian*, *The Times*, *El País* and *El Mundo*. The analysis shows that most metaphors coincide with those found in scientific articles and there are few creative explanatory images in the English and Spanish popularisations. The English articles make greater use of the suicide image whereas the Spanish texts rely more on variants based on "cell death" and "die". In certain contexts, some metaphors are ambiguous and confuse rather than clarify the process while others might not be considered the most appropriate choices.

Keywords: apoptosis, metaphor, popularisations, recontextualisation, press, corpus studies, English, Spanish

> The writer used a chilling phrase to describe traumatic hair-cell loss: 'exposure to damaging drugs or noises causes these hair cells to die with a kind of suicide program. They basically commit suicide in your ear'. Is it possible, after all, that that rock band at Fillmore West provoked mass suicide in my inner ears?
>
> David Lodge, *Deaf Sentence*

1. Introduction

This chapter explores different metaphorical expressions that are used in the description of a cellular process named apoptosis, which is a kind of cell death. In the quotation above, from David Lodge's novel *Deaf Sentence* (2008, p. 171), the protagonist, who suffers from a type of hearing impairment, qualifies the metaphor attributed to the process of apoptosis, *suicide program*, as *chilling*. And he is

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left somewhat perplexed at the idea of having experienced a *mass suicide* without having noted anything. The suicide metaphor for apoptosis may well sound puzzling to a layman's ear, but experts in the field have also shown some concern about the potential ambiguities that this, and other apoptosis-related metaphors, may give rise to.

The aim of this chapter is twofold. After briefly clarifying and defining apoptosis, it provides an overview of the metaphors that are associated with this process in the specialised literature. This overview is based on the comments made by a number of experts in the field who have drawn attention to the metaphorical nature of these terms and have expressed some degree of concern about the ambiguities they carry. The second part illustrates how these metaphors can also prove problematic in less specialised genres. It includes the quantitative and qualitative analysis of the metaphorical expressions for apoptosis that have been identified in a bilingual, English and Spanish, corpus of press popularisation articles on cancer and considers how helpful some of the metaphors are in the explanation of the process. This corpus was compiled for a broader investigation, but has been considered suitable for the present analysis since the evasion of apoptosis is key in cancer formation and the subset of articles dealing with this process is large enough to carry out the detailed qualitative analysis presented here.

2. Apoptosis

Apoptosis is a highly complex biological process. Thus, a full account of the intricate biological interactions taking place when a cell goes into apoptosis is beyond the scope of this study. However, a few basic notions in relation with this process might be required for a better understanding of this chapter.

It is customary knowledge that cells are the smallest living organism and, as such, after they are born, they grow, reproduce and finally die. There are different types of cell death, but the most common type is apoptosis. In contrast to human death, which is normally seen as a tragic and negative event, the death of the body's cells is not problematic because they are constantly renewing themselves. In other words, we do not run out of cells, and this process is essential for the correct functioning of the organism. Apoptosis plays a crucial role in the normal development of the body. For instance, during pregnancy, the webbed tissue connecting the toes and fingers is removed by apoptosis, leading to the correct formation of the digits. The process is also essential to maintain tissue balance (homeostasis). In a human adult, about 50 billion cells die daily and the body replaces an estimated 70 kg of cells annually to ensure that the amount of tissue remains stable. Finally, apoptosis is key in the removal of damaged cells from the system. Under normal conditions, if mistakes occur during cell division, the damaged cell will undergo apoptosis to avoid harming the rest of the organism. Therefore, in spite of the general negative connotations of death from our human perspective, the death of our cells should be regarded as beneficial and necessary for the correct functioning of the body.

The deregulation of apoptosis may lead to the development of pathological conditions. For instance, degenerative diseases like Alzheimer's, Huntington's and Parkinson's are associated with an excess of apoptosis, whereas cancer is related to a lack of apoptosis taking place (Pelengaris & Khan, 2006, p. 252). In contrast to healthy cells, cancer cells evade apoptosis and thus continue to divide, resulting in an uncontrolled proliferation. Currently, an increasing amount of research is devoted to the understanding of this process and to the identification of substances that can trigger this mechanism.

Hanahan and Weinberg (2000) describe the process of apoptosis as follows:

> Cellular membranes are disrupted, the cytoplasmatic and nuclear skeletons are broken down, the cytosol is extruded, the chromosomes are degraded, and the nucleus is fragmented, all in a span of 30–120 min. In the end, the shriveled cell corpse is engulfed by nearby cells in a tissue and disappears, typically within 24hr
> (Hanahan & Weinberg, 2000, p. 61)

Thus, in non-technical terms it could be said that what happens in apoptosis is that the different cellular components are neatly broken down and cleared up by nearby cells leaving no trace behind.

The process of apoptosis was first observed in the nineteenth century (Lockshin & Zakeri, 2001), but the actual term was not coined until 1972, when a team of anatomical pathologists, Kerr, Wyllie and Currie, introduced it in an article written for the *British Journal of Cancer*. In a footnote, they acknowledged that Professor Cormack of the University of Aberdeen had suggested the term and explained that "the word 'apoptosis' (ἀπόπτωσισ) was used in Ancient Greek to describe the 'dropping off' or 'falling off' of petals from flowers, or leaves from trees" (Kerr et al., 1972, p. 241). The extant literature is not too clear as to which aspects motivated the coinage of the term. Cortés Gabaudan (2009) clarifies that the word is a compound with a prepositional element apó (απó) meaning "from", and a noun ptôsis (πτωσισ) meaning "fall". The anteposition of the prepositional element specifies that the process takes place in a gradual manner. Analogously, in apoptosis cellular elements disappear progressively. Lockshin and Zakeri (2001) specify that the term was coined to emphasise the homeostatic or balanced relationship between the death and the birth of cells (Lockshin & Zakeri, 2001, p. 547):

> to focus attention on the yin-yang relationship of death to birth (that is, homeostasis is not maintained unless the loss of cells equals the birth of cells). The three [Kerr, Wyllie and Currie] argued that the ritualistic nature of cell death implied an

> organized and conserved mechanism: cell death or apoptosis was an aspect of life like any other (Lockshin & Zakeri, 2001, p. 547)

Moreover, Majno and Joris (2004, p. 210) comment that the term was introduced to conjure up the morphological contrast between death by apoptosis, whereby cells perish one by one in a process resembling the leaves falling from the trees, and the phenomenon of massive cell death, or necrosis.

Whatever the actual motivation might have been, the term "apoptosis" reveals itself as an image metaphor based on the resemblance between the image of leaves and petals falling and the appearance of a cell undergoing apoptosis. However, it should also be mentioned that from its inception, it was a dead metaphor (at least for people unfamiliar with the Ancient Greek language) (Eubanks, 2000, p. 71). Therefore, in the remainder of the chapter, apoptosis will not be treated as metaphorical, but as the target domain to be explained.

3. Cell death metaphorical expressions in specialised genres

The different terms employed to refer to or describe cell death in general – and apoptosis in particular – have caught scientists' attention, and the lack of systematicity and consistency in their use has led to the creation of a Nomenclature Committee on Cell Death (Kroemer et al., 2005). The scientific community has also drawn attention to the metaphorical nature of the terms used for cell death, and experts in the field have discussed the connotations or associations that these expressions may evoke (Ameisen, 2002, 2003; Melino et al., 2010). In this respect, Ameisen (2002) has expressed a common concern found in scientific circles, which is that of mistrust towards metaphorical language. In his article on cell death, Ameisen (2002, p. 368) quotes Lewontin, who warns that although "it is not possible to do the work of science without using a language that is filled with metaphors […] the price of metaphor is eternal vigilance" (Lewontin, 2000, pp. 3–4).

In order to illustrate some of the metaphors used to discuss apoptosis in the specialised literature, I include the following definition from an article published in the scientific journal *Nature*:

> The most common and well-defined form of *programmed cell death* (PCD) is *apoptosis*, which is a physiological '*cell-suicide*' programme that is essential for embryonic development, immune-system function and the maintenance of tissue homeostasis in multicellular organisms
> (Okada & Mak, 2004, p. 592, my emphasis)

The three terms highlighted in italics in the Okada and Mak quotation are metaphorical. As mentioned above, "apoptosis" is a case of catachresis, or lexical gap filling, and whereas "programmed cell death" is not explicitly singled out and, thus, appears to be fully accepted by the scientific community, the expression "cell-suicide" is placed between scare quotes, signalling that it should not be taken literally. Experts in the field of cell death have emphasised that these terms, although often used interchangeably, are not synonymous:

The terms 'programmed cell death', 'cell suicide' and 'apoptosis' have each played a major role in expressing crucial conceptual advances concerning cell death and in promoting interest for the field, but it should also be noted that none of these terms are synonymous, that each one carries its own metaphors and philosophical implications, and hence some degree of ambiguity (Ameisen, 2002, p. 368).

As will be shown, these expressions travel from specialised to more popular genres. Although in popularisation literature it may not be necessary to make fine-grained distinctions, it is nevertheless relevant to track down the origin, meaning, implications and potential ambiguities of the technical metaphors used in the field of cell death.

3.1 Programmed cell death

As mentioned above, the term "programmed cell death" is often used as a synonym for apoptosis. Nevertheless, although apoptosis is a kind of programmed cell death, not all programmed cell deaths occur by apoptosis. The term "programmed cell death" was in fact introduced in the 1960s – before "apoptosis" was coined – in the field of embryology with the meaning "to die on schedule" (Lockshin & Zakeri, 2001, p. 546; Majno & Joris, 1995, p. 11). Apparently, there are two types of programme: one which indicates to the cells that they are ready to "die"; and one which specifies how to bring about the death, for instance, by apoptosis. In the experts' own words: "The genetic program of programmed cell death is a clock specifying the time for suicide, whereas the genetic program of apoptosis specifies the weapons (the means) to produce instant suicide" (Majno & Joris, 1995, p. 11).

Nevertheless, Ameisen (2002) notes that the etymological origin of the word programme ("pre-written") is ambiguous in biology because it suggests too strict a link between design and finality and confuses the existence of pre-written genetic information with the many ways this can be implemented by the cells and the body:

Accordingly, it is not the individual fate of each cell, its survival or its death, that is programmed (pre-written), but the capacity of each cell to induce or repress its self-destruction, depending on its present and past interactions with the other cells that constitute the body, and on the integrity of its internal components (Ameisen, 2002, p. 368).

3.2 Cell suicide

The notion of cell suicide was developed in the 1950s after Christian de Duve (1959, p. 154) discovered the lysosome, an organelle located inside the cell. De Duve suggested that lysosomes might act like "suicide bags" which exploded, killing the cell from within as a result (Majno & Joris, 1995, p. 7). Apparently, this mode of cell death only took place in cells under very special circumstances (Majno & Joris, 1995), but the metaphor has remained present in the scientific literature.

There is a general impression among scientists that the term "cell suicide" is non-specialised and thus inappropriate for the specialised genres (Hidalgo Downing and Kraljevic Mujic, 2009, p. 72). However, although this metaphor may be less frequent than the term apoptosis or the expressions "programmed cell death" or "cell death", "cell suicide" is found in scientific discourse (Tercedor Sánchez, 2000; Sheard, 1997). Further support for this claim is provided by the fact that the metaphor is explicitly commented on in the scientific literature:

> If we use the term 'suicide', we bring in, subliminally, anthropological implications derived from the social and philosophical field. We could say that the cells commit suicide for the benefit of the organism (altruistic death with social implications). We could also say that the organism kills innocent cells for its own selfish interest (egotistic death). Here, we should consider the definition of 'self' of the cell (I, cell, kill myself for the benefit of the organism). But do genes, cells and organisms have a 'self'? (Melino et al., 2010, p. 5).

In a similar vein, Ameisen (2002) underscores the potential ambiguity of the anthropomorphic associations of the term while clarifying some misconceptions that it may give rise to:

> The concept of 'cell suicide' or 'self-destruction' also provides some level of ambiguity, not only because of its obvious anthropomorphic reference, but also because it favours a confusion between the act of initiating self-dismantling (that the cell indeed performs by activating an intrinsic cell death machinery) and both the 'decision' to kill itself and the implementation of the death process
> (Ameisen, 2002, p. 368)

Thus, the use of "suicide" appears to be in part justified since this metaphor emphasises the fact that the cell has all the necessary components to bring about its death. Nevertheless, what triggers apoptosis – in Ameisen's terms the "decision" to bring about the death of the cell – is a different matter. From what I gather, the process can take place via two signalling pathways, extrinsic and intrinsic, which ultimately activate the caspases (Ameisen's "intrinsic cell death machinery"), a set of enzymes which start dismantling the cell from within. A review of the range of components which activate the extrinsic and intrinsic pathways is beyond the scope of this study. Nevertheless, it should be mentioned that the scientific community is seeking to arrive at a complete understanding of the mechanisms of apoptosis in order to find ways to activate the apoptotic pathways in cancer cells. In this sense, as Spaeth (1998) has argued, a more apt metaphor for some deaths by apoptosis would be that of "murder":

> Apoptosis has been called "cell suicide" […] though this characterisation is partially misleading. In some instances the cell has been preprogrammed to die, and, indeed, this could be considered as a type of suicide. However, apoptosis in many cases is triggered by some outside stimulus […] so the metaphor is properly closer to a forced suicide, or murder (Spaeth, 1998, p. 9).

The suicide metaphor is often classed as alien to scientific discourse (Hidalgo Downing & Kraljevic Mujic, 2009, p. 72). Nevertheless, as shown in the experts' discussion, it has played an important role in advancing the field of cell death, and thus it could be argued that for some time the metaphor had a theory-constitutive function: i.e., metaphors that are "an irreplaceable part of the linguistic machinery of a scientific theory", allowing scientist to explore new concepts, discuss them and express "theoretical claims for which no adequate literal paraphrase is known" (Boyd, 1993, p. 486). Boyd (1993) argues that cognitive psychology was influenced by computer metaphors beyond the mere addition of terminology. He emphasises that the metaphors also had an impact on the field by shaping the predictions and hypotheses formulated. For instance, if the brain is viewed as a computer, thought can be seen as some kind of "information processing". The analogy may also imply that there are "preprogramed" cognitive processes involved and it makes predictions about how information is memorised since it could be "encoded" or "indexed" in a "memory store" or "labelled" and "stored" as "images". Finally, the framing also raises important issues to consider, such as whether an internal "brain language" can be considered to exist.

3.3 Cell death

Another term found in the scientific literature is that of "cell death" which can also appear in its verbal form (cells "die"). Although apoptosis is a form of cell death, there are many other ways in which a cell can die. Nevertheless, a question which could be raised is whether cells actually die. In this respect, the scientific literature takes the expression to be a metaphor:

> 'Death', for example, implies that there is only one death, that there is nothing after death, and that it is the final event. However, dead cells might 'die' more than once (erythroblasts 'die' when they lose their nuclei and mitochondria to become erythrocytes, and then 'die' again when they are eliminated from circulation;

> keratinocytes 'die' when differentiated and lose their nuclei and mitochondria, and then 'die' again during desquamation […]). These cells remain active and functional after 'partial death' (Melino et al., 2010, p. 5)

As a result, the notion of cell death has been revised and redefined on various occasions. The Nomenclature Committee on Cell Death (NCCD) has written three reports to unify the definitions and terminology regarding cell death. While the first two devoted sections to the definition of cell death, bearing the headings "Dead cells" (Kroemer et al., 2005, p. 1464) and "When is a cell 'dead'?" (Kroemer et al., 2005, p. 1464, 2009, p. 4), the third report does not include further comments on the notion as it presumably no longer required clarification (Galluzzi et al., 2012). The quotation below is a fragment from the second report where the term is defined:

> In the absence of a clear, generally accepted view of the 'point-of-no-return', the NCCD suggests that a cell should be considered dead when any of the following molecular or morphological criteria is met: (1) the cell has lost the integrity of its plasma membrane, […] (2) the cell, including its nucleus, has undergone complete fragmentation into discrete bodies […]; and/or (3) its corpse (or its fragments) have been engulfed by an adjacent cell in vivo. Thus, bona fide 'dead cells' would be different from 'dying cells' that have not yet concluded their demise (which can occur through a variety of biochemically distinct pathways)
> (Kroemer et al., 2009, p. 5)

The consensus among the scientific community on the meaning of a technical term is common in the process of science making. As argued by Semino (2008, p. 154), "when particular metaphors are adopted within a scientific community, they tend to evolve towards greater and greater clarification of what aspects of the source apply to the target". As knowledge of the target domain increases, the meaning of technical metaphors relies less and less on correspondences from the source domain, the metaphors gain new and specialised meanings and, in the end, the terms may no longer be perceived as metaphorical by the scientists (Semino, 2008, p. 133). This is arguably the case of what has happened in the representation of the death of cells and what it means for cells to "die".

This overview of the different metaphorical expressions that are used for apoptosis and which have played a major role in the development of the field of cell death indicates that cells are (a) personified (through the expressions "cell death" and "cell suicide"), or (b) portrayed via "mechanistic" metaphors (with the expression "programmed cell death"). As will be shown in Section 5, such metaphorical expressions are also exploited in popularisation articles for the elucidation of the process of apoptosis, and some of the ambiguities that arise in specialised genres may be carried over to more popular accounts.

4. Materials and methods

4.1 Corpus

The corpus used in this study was originally compiled for a broader investigation with the general aim of exploring the use of metaphor in cancer popularisation articles. The articles eligible for inclusion were drawn from the electronic sites of four newspapers and dealt with advances in the field of cancer research. The corpus is bilingual, English-Spanish, and consists of 300 popularisation articles compiled from *The Guardian*, *The Times*, *El País* and *El Mundo*.

The process of apoptosis did not feature in all of the articles in the corpus. Therefore, a subset of the articles that explicitly dealt with apoptosis was selected for the present study. Given that the size of the corpus was fairly manageable, this selection was carried out through the reading of the articles. Of the 150 texts in the English subcorpus 29 articles (17 from *The Guardian* and 12 from *The Times*) included reference to the process of apoptosis (Appendix 1). In the Spanish subcorpus, the process also featured in 29 texts (14 from *El País* and 15 from *El Mundo*) (Appendix 2). Thus the subset of articles comprised a total of 58 texts.

4.2 Metaphor identification

Metaphor identification was broadly based on the Metaphor Identification Procedure (MIP) which was developed by the Pragglejaz Group (2007), with the aim being "to establish, for each lexical unit in a stretch of discourse, whether its use in a particular context can be described as metaphorical" (Pragglejaz Group 2007, p. 2). Briefly, the meaning in context for each lexical unit of interest in the text was established taking into account what comes before and after the lexical unit. It was then determined whether the lexical unit has a more basic contemporary meaning in other contexts than the one in the given context. Basic meanings tend to be more concrete, related to bodily action, more precise, and historically older, but are not necessarily the most frequent meanings of the lexical unit. Basic meanings were established with the aid of dictionaries: *The Macmillan English Dictionary for Advanced Learners* (Rundell & Fox, 2002) for the English subcorpus and the *Diccionario de Español Actual* (Seco et al., 1999) and the *Diccionario de la Lengua Salamanca*, a Spanish learner's dictionary (available online at: http://fenix.cnice.mec.es/diccionario/). If the contextual meaning contrasted with the basic contemporary meaning but could be understood in comparison with it, the lexical item of interest was marked as metaphorical (Pragglejazz 2007, p 3).

Location of relevant metaphorical items was performed with the Wordsmith Tools package (Scott, 2010) by generating an alphabetical wordlist from the corpus which was examined to check for the presence of lexical items of interest (e.g. apoptosis, death, die, suicide, self-destruct). Once the texts dealing with apoptosis had been identified, concordance lists were generated for the lexical items of interest and these were viewed in context in order to establish metaphorical use as opposed to a more basic meaning and to determine that the expression referred to the aspect of cancer under study as opposed to any other unrelated domain. The concordance lists were then refined by eliminating those concordance lines not relevant to the analysis. Definitive lists of the relevant metaphorical expressions for each newspaper and subcorpus were then compiled in order to carry out the quantitative and qualitative analyses.

5. Analysis

5.1 Quantitative analysis of metaphors of apoptosis

The technical term "apoptosis" was explicitly mentioned in 9 of the 29 texts that make up the English subcorpus (5 from *The Guardian* and 4 from *The Times*). Thus, the process was more often referred to through metaphorical expressions. Table 1 shows the quantitative data for the most recurrent metaphorical expressions of apoptosis identified in the two English newspapers and accounts for the number of instances and the number of texts in which these appear.

Many of the expressions used metaphorically revolve around the notion of suicide (*commit suicide*, cell *suicide*, *kill themselves*, *destroy themselves*, *self-destruct*). As will be argued, although the suicide image is often perceived as less technical and thus more appropriate for popular genres (Hidalgo Downing & Kraljevic Mujic, 2009), it may not always serve the purpose of clarifying the process.

The suicide metaphor was the only one to be singled out by means of scare quotes (6 of a total of 18 instances). This not only indicates to the reader that the term should not be taken literally, but may also be because the image is somehow shocking:

(1) Tests showed that the treatment triggered a "*suicide*" response known as apoptosis in the cancer cells, causing them to *self-destruct*. (ti58)

Other metaphorical expressions relate to the notion of cell death (cell *death*, *death*, *die*), which is more generic than the concept of suicide. Although cells can be considered living organisms that cease to exist at some point, I have labelled the term as metaphorical because the death of a cell is different from that of other living organisms, whether human, animal or plant. Furthermore, as argued above, in the scientific literature on cell death, the term is regarded as metaphorical, although

Table 1. Metaphorical expressions for apoptosis in the English subcorpus

	The Guardian		*The Times*		Combined	
Metaphorical expression	**No. texts**	**No. instances**	**No. texts**	**No. instances**	**Total texts**	**Total instances**
Commit suicide	7	8	4	4	11	12
Cell suicide	0	0	3	4	3	4
Suicide + noun	1	1	1	1	2	2
Cell death	5	7	2	3	7	10
Programmed cell death	2	2	1	1	3	3
Death	3	3	1	1	4	4
Die	4	6	4	5	8	11
Self-destruct (programme)	0	0	3	3	3	3
Kill themselves	2	2	0	0	2	2
Destroy themselves	1	1	0	0	1	1
Weapon	0	0	1	1	1	1
Survival mechanism	1	1	0	0	1	1
Defence	1	1	0	0	1	1
Attack	1	1	0	0	1	1
Total	17*	33	12*	23	29*	56

*The totals for the number of texts columns are not summative as texts may include images from more than one of the listed metaphorical expressions

its metaphoricity is rarely highlighted in any way (Melino *et al.*, 2010, p. 5), and, in fact, no instance of cell death in the English subcorpus was singled out by scare quotes. In addition, it appears that within the scientific community the question of whether a cell is "dead" is not as straightforward as it may seem (Kroemer et al., 2005, p. 1464). The following example illustrates how cells undergo a "special kind" of death, different from that of humans:

(2) Normal cells will *die* once they have broken down beyond a certain point. The researchers found, however, that cancer cells recovered once the chemicals were removed. They were killed irreversibly only once their nuclei began to disintegrate, which happens at the very end of cell *death*. (ti61)

The metaphor of *programmed cell death* is not frequent, with only 3 occurrences. This may be because the metaphor is perceived as more technical than the suicide metaphor and hence less suitable for popularised articles. In fact, this expression never appeared in isolation, but in combination with other linguistic metaphors that helped to clarify the concept. In Majno and Joris's (1995) terms, the *sell-by* *date* metaphor in (3) emphasises the timing schedule of the programme rather than the means by which it is carried out, which is expressed by *suicide*:

(3) Which genes have normal functions to suppress tumour growth and to look after the *programmed cell death* mechanism which ensures that cells past their *sell-by date* are neatly *persuaded* to *commit suicide*? (gu10)

Finally, other isolated linguistic metaphors were identified, including apoptosis as a *weapon*, a *survival mechanism*, a *defence* and an *attack*.

In the Spanish subcorpus, the technical term "apoptosis" was explicitly mentioned in 15 of the 29 texts dealing with this process (8 from *El País* and 7 from *El Mundo*). The term appears parenthetically in 8 texts. In these cases a metaphorical alternative is given first and then the technical name is provided. In only one text was the technical term not explained at all. Table 2 provides the quantitative data for the most recurrent metaphorical expressions identified for this process in the two Spanish newspapers and accounts for the number of instances and the texts in which they occur.

Table 2. Metaphorical expressions for apoptosis in the Spanish subcorpus

	El País		*El Mundo*		Combined	
Metaphorical expression	**No. texts**	**No. instances**	**No. texts**	**No. instances**	**Total texts**	**Total instances**
Muerte celular programada	5	5	3	3	8	8
Muerte celular	2	4	3	4	5	8
La muerte de las células	2	2	8	9	10	11
Morir	6	7	6	6	12	13
Suicidio	3	3	3	3	6	6
Suicidarse	3	4	0	0	3	4
Autodestruirse	3	4	0	0	3	4
Total	14*	29	15*	25	29*	54

*The totals for the number of texts columns are not summative as texts may include images from more than one of the listed metaphorical expressions

Although the instances are not numerous, it seems that the two newspapers have different preferences for referring to and explaining apoptosis. Whilst *El País* is more varied with regard to the metaphorical expressions used, *El Mundo* shows a tendency to resort to different phraseological variants containing the noun *muerte* ('death'), and it is less inclined to employ metaphorical expressions related to the concept of *suicidio* ('suicide'). As in the English subcorpus, in the Spanish texts the different metaphorical expressions appear in combination to explain the process of apoptosis.

The suicide metaphor is not too conspicuous in the Spanish subcorpus with 6 instances of *suicidio* ('suicide') and 4 of *suicidarse* ('to commit suicide'). It should also be noted that in *El Mundo* the expression of cells 'committing suicide' is not present, whereas in *El País*, and in the English subcorpus, it is more frequent, as is the concept of *autodestruirse* ('self-destruct'), which is also absent in *El Mundo*. The virtual absence of the 'suicide' metaphor in *El Mundo* may be attributable to the ideological slant of the newspaper, which is conservative and shows a close alignment with the Catholic Church. In strongly Catholic circles, suicide, like abortion, is a taboo topic.

In the following, I illustrate how the different expressions are combined to elucidate the process of apoptosis in a detailed account of a fragment from a sample text in the English subcorpus.

5.2 Analysis of a sample text

The excerpt contains the headline and first three paragraphs of the only text (gu34) in the English subcorpus which describes the process of apoptosis in detail.

Sample text

Scientists find molecule that *tricks* cancer cells into *dying*

Scientists have found a way to *trick* cancer cells into *committing suicide*. The new synthetic compound, which *removes* a molecular *safety catch* that *activates* the natural *executioner* in the body's cells, could lead to better treatments of cancers […].

The body has several *defences* against cells growing out of control and into tumours – one is to cause defective or dangerous cells to *commit suicide*. This natural process of *cell death*, called apoptosis, involves a protein called procaspase-3. When *activated*, procaspase-3 changes into an enzyme called caspase-3, which begins the *cell death*. In cancers, this *mechanism* is often faulty and cells can grow unchecked. Many types of cancer are *resistant* not only to the body's own signals for *cell death* but also to the chemotherapy drugs that try to mimic it.

But Paul Hergenrother […], has found a way around the natural biological process that *kickstarts* apoptosis – a synthetic molecule that directly *activates* procaspase-3. "This is the first in what could be a host of organic compounds with the ability to directly *activate executioner* enzymes."

This fragment exploits metaphorical language extensively to explain the scientists' achievement of prompting the process of apoptosis in cancer cells by means of a synthetic molecule. The text contains a number of personifications (*trick*, *dying*, *committing suicide*, *executioner*, *cell death*) and mechanistic metaphors (*molecular* *safety catch*, *activate*, *mechanism*, *kickstart*) as well as isolated examples relating to war and violence (*defences*, *resistant*).[1]

The text opens with a headline that personifies the two agents under discussion: the molecule (procaspase-3) and cancer cells. They are presented in direct interaction and cancer cells are said to be *tricked into dying* by the molecule.

The first sentence of the lead is similar to the headline but instead of *dying*, it states that cancer cells are *tricked into committing suicide*. Both expressions, *trick* cancer cells into *dying* or into *committing suicide* are metaphorical renderings of the process of apoptosis. The perhaps shocking nature of the statements may be justified by the rhetorical function of the loci they occupy in the text. The headline and lead summarise the news report, but also serve to attract the readers' attention. In the next sentence of the lead, the journalist introduces mechanistic metaphorical expressions to explain how the *death* is brought about: the molecule *removes* a molecular *safety catch* and thus *activates* a natural *executioner* in the body's cells. The metaphorical expression molecular *safety catch* could be evoking the image of a firearm or some other machine in general. However, since in the previous sentence cancer cells were said to *commit suicide*, it makes sense to think of a gun. The natural *executioner* in the body's cells refers, as mentioned later in the article, to caspase-3. The caspases are a family of enzymes which, once activated, start degrading the cells' organelles. There are two types of caspases 'initiator' and 'effector', or 'executioner', caspases (Pelengaris & Khan, 2006, p. 261). Caspase-3, which belongs to the second type, is personified as are the other relevant agents in the article: the molecule and cancer cells. Since the process takes place within the cell, the motivation for the ambiguous suicide image introduced in the previous sentence is clarified: the cell has the intrinsic components to bring about its own death.

Apoptosis is a fairly specialised notion, probably unfamiliar to the lay audience. Therefore, in the second paragraph, the journalist introduces some basic information about the process which will serve as a background for the readers to understand the rest of the article. The process is portrayed as a bodily *defence* against the formation of tumours and the metaphor of cells *committing suicide* is repeated in the text. This is followed by the introduction of the specialised term "apoptosis", which is defined as "a natural process of *cell death*" immediately before the term is presented. The chain of reactions of one of the pathways leading to cell death is then explained. Finally, the fact that this *mechanism* is defective in cancer cells is also explicitly mentioned.

1. Although some of the metaphorical expressions such as *death* and *die* could also apply to animals and plants and, thus, it would be inappropriate to talk about personification, I have classified these terms under this label for the sake of simplicity.

In the third paragraph, the journalist goes back to the investigation being reported and provides further information about the experiment. The scientists have found another way to *kickstart* apoptosis. This mechanistic expression is consistent with other linguistic metaphors introduced previously: apoptosis is a *mechanism*, procaspase-3 becomes *activated* and removes a molecular *safety catch*.

This short fragment shows how both personification and mechanistic metaphors are used systematically and in combination to elucidate the process of apoptosis and the scientific discovery made in this field. The three agents – the molecule, cancer cells and caspases – are personified and more specific complex biological relations are explained by drawing on machine metaphors.

5.3 Problematic examples

As mentioned in the above analysis, the use of the suicide metaphor may be justified because the text explicitly mentions that the molecular machinery to bring about the death of the cell resides within the cell itself: "the new synthetic compound, which *removes* a molecular *safety catch* that *activates* a natural *executioner* in the body's cells". In addition, the metaphor should be analysed within the rhetorical structure of popularisation articles. Thus, the personification of the molecule which *tricks* cancer cells is justified by the fact that it serves to condense and summarise the outcome of the research while the shocking suicide image helps to catch the readers' attention.

However, the use of metaphorical expressions related to the concept of suicide may be problematic depending on the context in which they are used. Two major problems have been identified, especially in the English subcorpus, in which suicide-related metaphors are more frequent (Tables 1 and 2). For the sake of clarity, I will illustrate each of the problems first with English examples and then I will show how similar contexts are dealt with in the Spanish texts.

The first problem can be seen in the following excerpts, which have been extracted from two texts that, beyond the inclusion of the suicide metaphor, do not develop the explanation of the process of apoptosis:

(4) "Instead of going on dividing indefinitely, the cells float free and then go into apoptosis – the process of *cell suicide*." Normal cells *commit suicide* at the end of their life cycles. But when this process goes wrong and cells continue dividing unchecked, the result is a tumour. (ti14)

(5) AITC [allyl-isothiocyanate] seems to prevent cancer cells becoming "immortal", the property that makes them different from healthy cells which "*commit suicide*" instead of dividing infinitely. (gu18)

In Examples (4)–(5) healthy cells are expected to *commit suicide* – it is the normal way to *go*; otherwise, the result is a tumour. In scientific genres, the suicide image has proved useful for theorising about and explaining cell death in spite of the potential ambiguities which may arise from its usage (Ameisen 2002, p. 368; Melino *et al.*, 2010, p. 5). After all, scientists have sufficient knowledge of the target domain to interpret the metaphor correctly (Semino, 2008, p. 139). In the context of popularisation articles, however, since the motivation of the metaphor is not normally explained (cf. sample text above), the reader may be left somewhat puzzled. As lay readers rely on their knowledge of the source domain to make sense of the target (Semino, 2008, p. 139), the idea that the normal way for healthy cells to *die* is by *committing suicide* may not be easy to decode.

As regards humans, although cultural differences may apply here, suicide is perceived as an unnatural misfortune. The most natural way to *go* is through old age or disease. Analogously, if cells are to be personified, and provided that the article is not going to delve any deeper into the process of apoptosis and justify the motivation of the suicide metaphor, a more transparent way of portraying the process to the lay reader would be to say that cells *die*:

(6) The problem with cancer cells is their immortality. While other cells live their allotted span, *die* and are replaced, cancer cells carry on dividing. (gu17)

Another possible limitation of the metaphor is that it may be difficult to comprehend why the *suicide* of a normal cell should be beneficial to the organism. In our culture, suicide is often associated with the "premature" death of someone who died too young and in vain, thus throwing his or her life away. Thus, it is difficult to understand, from our frame of reference, why such an asocial behaviour would benefit the rest of society, or for our purposes, the organism.

The second problem arises in those examples where different substances or biological agents are presented in direct physical or verbal interaction with the cancer cells. Take the headline and the lead of the sample text:

(7) Scientists find a molecule that *tricks* cancer cells into *dying*. (gu34)

(8) Scientists have found a way to *trick* cancer cells into *committing suicide*. (gu34)

In the analysis of the sample text, I argued that this use may be justified by its location in the headline and lead and the metaphor might have been expressed in this way to catch the readers' attention. In addition, the ambiguous sentences are clarified in the rest of the article. However, this is not always the case in other numerous examples in which cancer cells are said to be *persuaded*, *made, forced, told*, or *induced* to *commit suicide* or *self-destruct*, or *jolted* or *coaxed* into doing so:

(9) Programmed cell death mechanism which ensures that cells […] are neatly *persuaded* to *commit suicide*. (gu10)

(10) Using very short, very powerful electric shocks, researchers are developing a way to *jolt* cancer cells into *committing suicide*. (gu16)

(11) Ginger seems to offer a two-pronged *attack* on cancer cells. It *makes* them *commit suicide*, known as apoptosis. (gu31)

(12) A natural survival mechanism called apoptosis, in which damaged and potentially cancerous cells are *forced* to *commit suicide*. (gu47)

(13) An anti-tumour protein which puts cells into hibernation or *makes* them *commit suicide*. (gu56)

(14) the "zapped" cells send out signals which *tell* their neighbours to *commit suicide*. (ti10)

(15) If cancer is detected, the computer orders the release of a single-strand DNA molecule designed to *induce* cancer cells to *self-destruct*. (ti13)

(16) The chemical […] has been found to *coax* cancer cells into *committing* a form of *suicide* by preventing them from repairing themselves when they come under *attack*. (ti20)

All of these Examples (9)–(16) reflect the specification of the "means" by which apoptosis is carried out as opposed to the "timing" of the event (Majno & Joris, 1995, p. 11), and they emphasise the intrinsic "capacity" of the cell to induce or repress its self-destruction (Ameisen, 2002, p. 368). Examples (9), (12) and (13) explain how in the normal process this capacity is activated by means of interactions that take place within the organism. In contrast, in (10), (11), (15) and (16), in which apoptosis is restored, the process is initiated from outside by the external stimuli provided by chemical agents, radiation or electroshocks. The "collective suicide" in (14) is an exceptional case in that the cells affected by the external agent (radiotherapy) interact with adjacent cells to reduce or eliminate the tumour without damage to healthy cells.

All the examples involve a causal relation which is represented metaphorically either by a communication verb – explicitly with *persuade*, *tell* and *coax* and implicitly in the case of *induce* – or by a verb expressing coercion or violence as in *force* and *jolt*. The delexicalised verb *made* in (11) can also be interpreted in the light of violence as it occurs in the context of an *attack*. Thus, only *make* in (13) can be interpreted as a neutral causal relation devoid of any violent associations.

Metaphors of violence are common in the discourse of cancer, but metaphors related to language and communication are also frequent in cell biology, both in relation to the genetic code (Knudsen, 2003) and to express interactions between biological entities (van Rijn-van Tongeren, 1997).

However, it is debatable whether these personifications, when combined with the suicide image, are the most appropriate representations of causality to explain and clarify the process of apoptosis. Firstly, a suicide is the voluntary decision adopted by an individual to end his or her life. While some verbs expressing more neutral causal relations might be acceptable (*made*, *induce*), neither *persuasion* nor *coercion* seem appropriate since a forced suicide could be more reasonably termed a murder, as has also been pointed out in the scientific literature (Spaeth, 1998, p. 9). Therefore, to say simply that cells are *caused* (or some other neutral verb) to *die* would be less ambiguous. Take the following example:

(17) "If you switch it [molecular mechanism] on it does two things – it *induces* the cells to *die*". (gu49)

As shown in example (3) above, different metaphors (*programmed* and *sell-by date*) may be combined to help clarify the process. The use of alternative metaphors to explain complex phenomena has been said to be important to facilitate comprehension in pedagogical texts (Semino, 2011, p. 151, Cameron 2003, p. 39). In addition, the use of alternative expressions may be stylistically motivated to avoid repetition. Nevertheless, the combining of different metaphors should always be carefully examined since this does not necessarily elucidate the process under discussion:

(18) When the drug is administered to patients, it will affect all cells, but when it is withdrawn healthy cells will continue to grow while cancer cells will go into a process of *cell death*, or "*suicide*" (ti23)

In (18) apoptosis is explained by the combination of the expressions cell *death* and *suicide*. Since the text does not delve any deeper into the implications of apoptosis, in my view, the perhaps gratuitous inclusion of the suicide metaphor at the end complicates the issue rather than helping to clarify the process.

In the Spanish subcorpus the notion of cells committing suicide is less frequent (Table 2). In the three texts from *El Mundo* in which the suicide image appears, it is singled out by the use of scare quotes and hedges, indicating to the reader that it should not be taken literally. A further important aspect of the use of this metaphorical term is that the cells are not personified or said to commit suicide. In (19) it is a *regression mechanism* mediated by a kind of cellular "suicide", in (20) the metaphor is also "mechanicised" and the cells are said to start a *controlled suicide* *programme* and in (21) the death of the tumour cell is said to be brought about by a kind of *suicide programme* called apoptosis:

(19) *En el segundo de los trabajos […], el* mecanismo de regresión *observado en los ratones era diferente, y estaba mediado por una especie de* 'suicidio' *celular en el caso de los animales con linfoma*. (em26)
'In the second of the studies […], the *regression mechanism* observed in the mice was different, and it was mediated by a kind of cellular '*suicide*' in the case of the animals with lymphoma.'

(20) *De hecho, aclara este especialista, sólo una pequeña proporción de estas células tiene la capacidad de* iniciar *metástasis en otros órganos del cuerpo, y muchas de ellas* inician *un* programa de suicidio controlado *una vez que alcanzan el torrente sanguíneo*. (em37)
'In fact, clarifies this specialist, only a small proportion of these cells has the ability to *start* metastasis in other organs in the body, and many of them *start* a *controlled suicide programme* once they reach the bloodstream.'

(21) *Finalmente, esta autofagia provoca la* muerte *de la célula tumoral mediante una especie de* suicidio programado *llamado apoptosis*. (em61)
'Finally, this autophagy causes the *death* of the tumour cell through a kind of *programmed suicide* called apoptosis.

It should also be mentioned that, in contrast to the personification observed in the English texts, the verbs of causation accompanying the suicide image in these examples, whether referring to artificial induction of the process, as in Examples (19) and (21) or to normal cell function as in (20), are relatively neutral: *mediar* ('mediate'), *iniciar* ('start') and *provocar* ('provoke'). In this last context, Spanish *provocar* does not carry the same aggressive connotations as its English counterpart.

In *El País*, only one text portrays "normal" cells as *committing suicide*, but they are said to be *driven* artificially to do so:

(22) *Hasta ahora, era un hecho contrastado que las células normales a las que se* conduce *de forma artificial a su* suicidio *alcanzan un punto de no retorno tras el cual tienen que* morir, *incluso en el caso de que se detenga la apoptosis artificial*. (ep68)
'Until now, it was a verified fact that normal cells which are artificially *driven* to their *suicide* reach a point of no return after which they have to *die*, even if artificial apoptosis is stopped.'

In two examples, damaged or cancer cells are said to commit suicide or to self-destruct (*autodestruirse*), but this is because they are "altered" or "have found" that they have made a mistake:

(23) *Hay cambios que permiten a las células seguir multiplicándose, lo cual las hace casi invulnerables, y otros que les permiten seguir viviendo cuando están* alteradas*; por lo general las células* alteradas se suicidan. (ep34)
'There are changes that allow cells to continue multiplying, which makes them practically invulnerable, and others that allow them to continue living when they are *altered*; in general, *altered* cells *commit suicide*.'

(24) *La molécula inhibidora* engaña *a la célula cancerosa haciéndole creer que se ha adherido a tejido sano, y ésta, cuando* descubre *el* fallo*, se* autodestruye. (ep51)
'The inhibitory molecule *tricks* the cancer cell, making it believe that it has bound to healthy tissue, and when the cancer cell *realises* the *mistake*, it *self-destructs*.'

The second problem, that is, the transparency of the examples where cells are said to be forced to commit suicide, is less frequent in the Spanish subcorpus. However, in a number of examples from *El País*, apoptosis is presented in this fashion:

(25) *Una molécula de importancia vital como el P53, conocida como el guardián del genoma, un oncogén supresor cuya misión es controlar los procesos de división y* muerte *celular (capaz de chequear si en el proceso de división se han producido daños irreparables en el ADN de la célula y de* ordenar *en consecuencia su* suicidio *o apoptosis).* (ep06)
'A molecule of vital importance like P53, known as the guardian of the genome, a suppressor oncogene whose mission is to control the processes of cell division and cell *death* (the gene is able to check whether during the process of division irreparable damage has been done to the DNA of the cell and as a result to *order* its *suicide* or apoptosis).'

(26) *Un mecanismo por el que se* induce *a la célula no solo a* suicidarse *(la famosa apoptosis en las que se basan muchas de las investigaciones sobre el cáncer), sino a autofagocitarse.* (ep73)
'A mechanism which *induces* the cell not only to *commit suicide* (the famous apoptosis on which many cancer studies are based), but also to go into autophagocytosis.'

(27) *El Yondelis actúa sobre cinco nucleótidos del ADN de la célula cancerígena, reclutando unas enzimas que* consiguen *que se* suicide *y, por tanto, deje de dividirse sin control.* (ep52)
'Yondelis acts on five nucleotides of the cancer cell's DNA, recruiting enzymes that *make* it *commit suicide* and, thus, stop dividing without control.'

Example (25) is the first sentence of the lead of an article entitled "*Una molécula para que el cáncer* se suicide" ('A molecule which makes cancer *commit suicide*'), which is similar to the title of the cited sample text in the English subcorpus: "Scientists find molecule that *tricks* cancer cells into *dying*". However, in (25), apoptosis is not explained further so, in this particular example, the suicide image does not clarify the process; nonetheless, it probably serves the purpose of capturing the readers' attention.

In Examples (22) through (27), a tendency towards greater personification is evident in the verbs of causation accompanying the suicide image compared to those used in *El Mundo*. Thus, in (24) the inhibiting molecule *engaña* ('deceives' or 'tricks') the cancer cell brings about its demise, and in (25) the P53 molecule *ordena* ('orders') causes the suicide of the cell. This personification, however, is consistent with the communicative images that are typical of gene function descriptions in scientific genres. The external stimulus represented in Examples (22), (26) and (27) – *se conduce* ('be driven'), *se induce* ('be induced') and *consigue* ('makes' – literally 'achieves'), respectively – are also relatively mild compared to the English examples of "force" and "jolt".

Similarly, I have not identified any examples in *El Mundo* involving a "forced suicide" in the contexts in which cell death and programmed cell death appeared:

(28) *Dos nuevos trabajos […] emplean docetaxel, un agente quimioterápico que* favorece *la* muerte *de las células cancerosas por un mecanismo denominado apoptosis.* (em03)
'Two new studies […] use docetaxel, a chemotherapeutic agent which *favours* the *death* of cancerous cells through a mechanism called apoptosis.'

(29) *Se refiere a los oncogenes, que han ido demostrando su papel en ciertos tipos de tumores […], y que en circunstancias normales conviven en equilibrio con los supresores tumorales […], responsables de todo lo contrario: detectar mutaciones peligrosas, corregirlas y, llegado el caso,* ordenar *la* muerte *de las células.* (em05)
'It refers to the oncogenes, which have been shown to play their role in certain types of tumours […], and which in normal circumstances coexist in balance with the tumour suppressor genes […], which are responsible for the opposite effect: to detect dangerous mutations, to correct them and, if necessary, to *order* the *death* of the cells.'

(30) *Éste [un gen] es un importante elemento de la respuesta antiviral. En concreto,* estimula *la* muerte *de las células infectadas* (apoptosis). (em19)
'The latter [a gene] is an important element in antiviral response. In particular, it *stimulates* [i.e. *triggers*] the *death* of infected cells (apoptosis).'

(31) *Aunque ya se habían descubierto compuestos capaces de* activar *la* muerte celular *(apoptosis), su poca efectividad hacía sospechar a los científicos que las células del melanoma disponían de algún sistema de protección adicional. "Pensamos que teníamos que buscar otros mecanismos alternativos de acción para* provocar *la* muerte celular". (em67)
'Although compounds capable of *activating cell death* (apoptosis) had already been discovered, their scant effectiveness made scientists suspect that melanoma cells had an additional protective system at their disposal. "We thought that we had to search for other alternative mechanisms of action to *provoke cell death*"'.

Instead, different substances *favorecen* ('favour'), *ordenan* ('order'), *estimulan* ('stimulate'), *activan* ('activate') or *provocan* ('provoke') the death of the cells, which, as argued in the previous section, may be less ambiguous as they do not include reference to suicide or to self-destruction.

5.4 Creative examples

Although apoptosis is presented through fairly conventional metaphors in both subcorpora, mostly revolving around the notions of "death" and "suicide" combined with mechanistic images, some texts include more creative expressions to help to clarify different aspects of the process.

Example (32) is a quote from a scientist, in which he underscores in an original way by likening of cancer cells to the *living dead* that apoptosis is a natural process and that its evasion leads cells to an abnormal state:

(32) "In this sense, you can think of cancers as the *living dead*: they are made up of cells that should have been killed off but which somehow have not and which pass through the body with deadly consequences". (gu71)

In (32) the abnormal trait acquired by cancer cells – the evasion of apoptosis – is explained through an image which also emphasises an "abnormal" characteristic in the source domain. Of course, this should be read in the light of mythology and folklore. The metaphor of the *living dead* conjures up the idea of cancer cells as zombies – creatures that should have died but have managed to avoid perishing, thereby lingering in the world of the living (i.e. rest of the body). Nevertheless, it should be noted that, although from an explanatory or cognitive point of view the image could be said to be more logical and clarifying, from an emotional perspective, the living dead metaphor might be problematic, especially for cancer patients (Sontag, 1991). It may be distressing to some readers to think of cancer cells as zombies within their own body.

In a similar vein, in Example (3), which I discussed in Subsection 5.1 above, cells are said to have a *sell-by date*, after which they are persuaded to *commit suicide*. The *sell-by date* expression implies that cells are perishable and that beyond a certain point they no longer possess their optimal characteristics for their "correct" functioning in the organism. In addition, since products past their *sell-by date* should not be for sale, the expression suggests that cells past their *sell-by date* should not remain in the organism. More crucially, Ameisen (2002) noted the ambiguity of the notion of "programmed" in biology and in the context of cell death in particular because of the determinism implied by the term. In (3), this ambiguity is somehow neutralised. Apoptosis is to some extent a timed event (*sell-by date*); on the other hand, its actual completion is influenced by other factors within the cell environment.

The same is largely true in (33), where the notion of "programme" is conveyed by portraying cells with an internal *clock* and *timing mechanism* marking their lifespan. The clock with the timing mechanism in this example refers to the cell's telomeres, which are a strip of DNA at the end of chromosomes. Whenever a cell divides, the telomeres get shorter and shorter (*ticking down*) until they cannot divide any longer. This is when the cell is ready to die. Unlike healthy cells, cancer cells manage to subvert this *mechanism* and become immortal, but the researchers have found a way to *activate* it again:

(33) "We have found evidence of a new *mechanism* for *stopping* the *clock* on a cancer cell's *timer* and preventing its *life-span* from *ticking down*. It raises the possibility of starting the *clock* again and making cancer cells susceptible to *death* once more." (gu17)

Other isolated war and violence metaphors portray the process as a *weapon*, an *attack* and a *defence* or as a bodily *survival mechanism*:

(34) The chemicals *triggered* signals that caused apoptosis, a form of *programmed cell-death* that is an important *weapon* against cancer. (ti19)

(35) Ginger seems to offer a two-pronged *attack* on cancer cells: it makes them *commit suicide*, known as apoptosis, and self-digest, known as autophagy. It offers the hope that when one form of *attack* starts to fail the other will *kick in*. (gu31)

(36) The body has several *defences* against cells growing out of control and into tumours – one is to cause defective or dangerous cells to *commit suicide*. (gu34)

(37) They also looked for evidence of a natural *survival mechanism* called apoptosis, in which damaged or potentially cancerous cells are *forced* to *commit suicide* before they can form tumours. (gu47)

In these examples, less frequent metaphorical expressions appear in combination with the conventional images for apoptosis in specialised and popular genres (*programmed cell death* and *suicide*) in order to shed light on the different ways in which apoptosis is initiated. In (34) and (35) apoptosis is portrayed as a *weapon* and as an *attack* because external agents (chemical compounds) activate this process. In contrast, in (36) and (37) the emphasis is placed on the fact that the process is intrinsic to the organism – a *defence* and a natural *survival mechanism*. In addition, the causal relation that specifies the "means" whereby apoptosis is brought about is expressed by the more neutral *cause* in (36) whereas (37) uses the coercive *force*.

Although it might be fortuitous, an interesting pattern emerges in Examples (34) through (37): all four combine the personification of cancer cells with mechanistic and war and violence metaphors as shown in Table 3.

Table 3. Combination of metaphor systems to represent apoptosis

Example	Personification	Mechanistic	War and violence
23	(programmed) cell death	trigger	weapon
24	suicide	kick in	attack
25	suicide	out of control, safety catch removed	defence
26	suicide	survival mechanism	force

In (34) the personification is realised through the term *programmed cell death*, which also includes a mechanistic component. In (36) the expression *out of control* relates to the fact that in cancer cells the *safety catch* is constantly on, thus making them immortal, as pointed out in the discussion of the sample text.

Creative examples are also scarce in the Spanish subcorpus, and most appeared in *El País*. In (38), the process is described as a *sistema de garantía* ('quality control system'), which in my view is a felicitous metaphor expressing the notion that apoptosis ensures that defective cells are eliminated:

(38) *Los trabajos se centraron en como el THC [delta-9-tetrahidrocannabinol] inducía la* muerte celular programada *(llamada apoptosis). Este proceso, que no funciona con las células cancerígenas, actúa como un* sistema de garantía *del organismo que impide que se reproduzcan las células con errores.* (ep11)
'The studies focused on how the THC induced *programmed cell death* (called apoptosis). This process, which does not function with cancer cells, acts as

the organism's *quality control system* which prevents cells from replicating with errors.'

In the same fashion, Example (39) describes the process as a *mecanismo de control* ('quality control mechanism'):

(39) *Cuando la célula está sometida a varios tipos de estrés o ve dañado su ADN, estos genes lo detectan y* disparan *el proceso de apoptosis (*suicidio *celular* programado*) […]. Cuando estos genes fallan, la célula se queda sin el último* mecanismo de control *que puede evitar la aparición del cáncer*. (ep16)
'When the cell is under various kinds of stress or when its DNA is damaged, these genes detect it and *trigger* the process of apoptosis (*programmed* cell *suicide*) […]. When these genes fail, the cell is left without the last *control mechanism* which can prevent the development of cancer.'

Finally, in Example (40), the process is described as a *mecanismo de regresión* ('regression mechanism'):

(40) *En el segundo de los trabajos, […], el* mecanismo de regresión *observado en los ratones era diferente, y estaba mediado por una especie de* 'suicidio' *celular en el caso de los animales con linfoma y por la senescencia (un* freno *innato del organismo a la progresión de lesiones premalignas) en aquellos animales con sarcoma*. (em26)
'In the second study, […], the *regression mechanism* observed in the mice was different, and was mediated by a kind of cellular '*suicide*' in the case of the animals with lymphoma and by senescence (an innate *brake* of the organism on the progression of premalignant lesions) in the animals with sarcoma.'

This "regression mechanism" expression is a broader term as it has to cover both apoptosis and senescence, the latter being an apparently irreversible form of cell cycle arrest that prevents development of a tumor. Interestingly, the suicide metaphor is introduced by the journalist whereas in replies to specific questions a co-author of one of the studies states that in lymphomas the regression mechanism depends on the induction of *apoptosis (muerte celular programada)* 'apoptosis (programmed cell death)'. Thus, in this example, the journalist opts for what is perceived to be a more popular account of the process, whereas the expert resorts to the more technical expression.

The following two Excerpts (41), (42), from two different articles from *El País,* report a scientific discovery carried out by Spanish researchers. The scientists developed a strategy to activate apoptosis in addition to autophagy, another kind of cell death whereby lysosomes degrade proteins and organelles inside the cell.[2] In each of the two articles exemplified below, one of the scientists involved in the study is reported in a direct quote to explain the two processes:

(41) *"La apoptosis es una destrucción poco a poco. Es como si se cogen unas* tijeras *y se van* cortando las cadenas una a una. *Al autofagocitarse se crean vesículas (técnicamente llamadas endosomas) que van destruyendo los componentes de la célula a toda velocidad".* (ep73)
'"Apoptosis is a gradual destruction. It's like taking a *pair of scissors* and *cutting the chains one by one*. In autophagocytosis, vesicles (technically known as endosomes) are formed and destroy the cellular components as fast as possible".'

In (41), the writer uses the quote by the scientist to illustrate apoptosis as a process in which the DNA chains are progressively shortened as if they were cut with scissors. Autophagy, on the other hand, is explained in non-metaphorical language. We can observe the opposite pattern of explanation in the second article from *El País*, shown in Example (42) below. Here, the process of apoptosis as a slow form of *killing* is barely elaborated on. Instead, the article uses the quote by the scientist to draw on a striking set of images to explain autophagy:

(42) *Primero, van matando a la célula anfitriona poco a poco (un proceso de* muerte programada *que se llama apoptosis). Luego, se produce una especie de "autocanibalismo": la célula cancerígena se autofagocita, indica Soengas. "Es como si en un coche de carreras [la célula tumoral] metiéramos un mecánico y lo activáramos para que fuera metiendo en un saco las partes del motor del coche, hasta dejarlo inservible", explica la investigadora.* (ep71)
'First they gradually kill the host cell (a process of *programmed death* called apoptosis). Then a kind of "autocannibalism" occurs: the cancer cell autophagocytoses, explains Soengas. "It's like placing a mechanic inside a racing car [the tumour cell] and setting him to put all the parts of the car engine in a sack until it is rendered useless", explains the researcher.'

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2. Endosomes and lysosomes are specialised vesicles within eukaryotic cells ("true" cells with a membrane-bounded nucleus). Endosomes are smooth sacs within the cell which sort through the material brought to them and send it to the right place in the cell. Thus, in one pathway, cell receptors are separated from their ligands and returned to the cell surface, the other material being passed on to the lysosomes for further processing. Lysosomes contain digestive enzymes that break down worn-out cellular components or foreign material, such as bacteria, which may enter the cell. Thus, endosomes are a kind of sorting department and distribution centre whereas the lysosomes perform the disintegration or self-destruction of cellular and other material.

Auto-cannibalism is a common metaphorical expression for autophagy, a term which comes from the Greek language and literally means *auto-* 'self' and *-phagy* 'to eat or to swallow'. In the direct quote, Soengas uses an elaborate analogy whereby she likens the cell to a racing car with a mechanic inside who gradually dismantles the motor until the vehicle is rendered useless. The analogy set up by the researcher presents the process of autophagy in a manner that can be readily visualised by the readers. During this process, the cell is dismantled from the inside by the caspases, and the outer membrane of the cell is not disrupted; thus, with this type of cell death the extracellular environment is not disturbed (Pelengaris & Khan 2006, p. 252).

6. Discussion

This chapter has dealt with the analysis of the metaphorical expressions used to recontextualise and explain apoptosis in the corpus of press popularisations. Apoptosis is a complex biological concept first identified in the nineteenth century, and the term "apoptosis", which was not coined until 1972, is, in fact, a metaphor. However, for the purpose of this study, it was considered a scientific term and the target domain to be explained.

In specialised genres a number of metaphorical expressions (*cell death*, *programmed cell death* and *cell suicide*) are used to explicate the abstract theoretical implications of apoptosis and have become conventionalised when the molecular processes involved in apoptosis are discussed between scientists. Nevertheless, as noted by experts, their metaphorical nature may give rise to potential ambiguities due to their mechanistic (*programmed cell death*) and anthropological (*cell death* and *cell suicide*) associations.

The empirical results of the analysis indicated that in general terms, popular accounts of apoptosis in both the English and Spanish newspapers relied on metaphors similar to those employed in scientific genres, expanding them to include more colloquial variants (*kill* or *destroy themselves* and *autodestruirse*), and journalists only rarely resorted to creative images in their elucidation of the process. However, in terms of cross-linguistic variation subtle differences have been found.

The quantitative analysis revealed a tendency towards a greater use of the suicide image in the English subcorpus (24 of 56 instances) than in the Spanish subcorpus (14 of 54). In the Spanish texts there was a general tendency to prefer different variants centred on the noun *muerte* ('death') and the verb *morir* ('die'). In particular, only three instances of the suicide image were found in *El Mundo*, and a possible explanation for this disparity may lie in the ideological slant of the newspaper.

A detailed analysis of a sample text was presented to show how metaphorical language could be exploited extensively to delve into the process of apoptosis and explain it through a combination of personifications and mechanistic metaphors. In this particular text, it was argued that the potentially ambiguous suicide metaphor was justified not only because the motivation for the metaphor was explained, but also because the rhetorical function it performed in the article was to arouse a response in the readers and induce them to continue reading.

However, a contextual analysis of the suicide metaphor in other articles suggested that this formulation might not be the best choice among the available options, and two major problems emerged. First, a number of texts included the suicide image without clarifying either the motivation of the metaphor or the process of apoptosis. Moreover, suicide was presented as the normal way for cells to die, an aspect which may clash with the readers' general frame of reference. It could be difficult for readers to reconcile the negative or asocial connotations of suicide with the beneficial effects of apoptosis in normal development, maintenance of tissue balance and removal of damaged cells. In this respect, the Spanish examples, which relied less on the concept of suicide, proved less problematic than those in the English subcorpus; when cells were said to *suicidarse* ('commit suicide'), this was because something had gone "wrong" with them or they were "altered".

The second problem was seen in a number of examples that contained verbs of causation in combination with the suicide image to elucidate the means by which apoptosis took place. It was argued that these verbs, especially those related to the notions of violence and coercion complicated the explanation of the already obscure concept of apoptosis. The notion of "forced suicide" confused the cases in which apoptosis occurred through processes internal to the cell with those in which cell death was brought about through an external stimulus and, therefore, more akin to "murder". These infelicitous combinations may, in part, be due to a conflict of interest on the part of journalists who have a twofold aim of communicating and explaining science to a lay audience and of making their articles attractive to their readers, this latter aim often achieved through striking images in the headline or lead (Radford, 2009).

In the light of this discussion, the following suggestions could serve as guidance to science popularisers. In those contexts in which apoptosis is only one aspect of the scientific article, it might be best – as evidenced in the Spanish subcorpus – to use the more generic metaphor of "death" and its variants, and when combined with verbs of causation, to resort to verbs expressing less forceful causal relations. However, those texts in which apoptosis featured as the main topic to be explicated would require greater elaboration. In these cases, writers could exploit more provocative metaphors and combine them with other source domains (mechanistic or war and violence), taking care to ensure that the mappings are consistent with the processes to be explained.

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Appendix 1. English subcorpus

The Guardian	
gu01	Volunteer patients recruited to test cancer-busting viruses. James Meikle 04/01/2002
gu10	What does the biotech revolution mean? Gordon McVie 09/03/2003
gu13	Hope in ovarian cancer battle. Tim Radford 23/06/2003
gu14	Shell implants 'burn out' cancer cells. Tim Radford 04/11/2003

gu16	Electrical pulses might zap tumours. guardian.co.uk 18/03/2004
gu17	Ageing secret may yield cancer drug. Sarah Boseley 30/04/2004
gu18	Scientists reveal how vegetables help beat cancer. James Meikle 11/05/2004
gu31	Ginger raises new hope in fight against ovarian cancer. Polly Curtis 18/04/2006
gu34	Scientists find molecule that tricks cancer cells into dying. Alok Jha 28/08/2006
gu35	'Good' bacteria may help stop some cancers, say scientists. Ian Sample 07/10/2006
gu41	Genome study finds 100 new cancer genes. Alok Jha 08/03/2007
gu47	Coffee and plenty of exercise could cut risk of skin cancer. Ian Sample 31/07/2007
gu49	Cold virus may be used in fight against cancer. James Randerson 04/10/2007
gu56	'Suicide protein' could help treat melanomas. Alok Jha 08/02/2008
gu61	New drug can protect healthy cells during radiotherapy. Alok Jha 11/04/2008
gu62	Scientists solve riddle of arsenic cancer treatment. Alok Jha 14/04/2008
gu71	Scientists on brink of cancer treatment revolution. Robin McKie 04/10/2009
The Times	
ti10	Cancer treatment kills cells one by one. Mark Henderson 02/12/2003
ti13	A very, very small step to beating the Big C. Mark Henderson 29/04/2004
ti14	The bitter truth – why greens are good for us. Nigel Hawkes 11/05/2004
ti15	Hunter virus gives new hope on cancer. Jonathan Leake 30/05/2004
ti19	Apple a day keeps cancer away Nigel Hawkes. 19/10/2004
ti20	Drug giants pin hopes on 'tadpole' to fight cancer. Richard Irving 05/02/2005
ti23	Dublin scientists develop drug that kills cancer cells. Dearbhail McDonald 27/03/2005
ti25	Breast cancer: a drug right on target. Thomas Stuttaford 19/05/2005
ti45	Back to the start of it all. John Naish 10/02/2007
ti58	New trial using doxorubicin and brittle bone drug, bisphosphonate drug zoledronic acid, gives breast cancer hope. David Rose 13/08/2008
ti61	Survival tactic for cancer cells. Chris Smyth 05/01/2009
ti62	New drug olaparib offers hope to women with genetic breast cancer. David Rose 01/06/2009

Appendix 2. Spanish subcorpus

El país	
ep05	Un centro de Barcelona lidera los ensayos de nuevos fármacos contra el cáncer. Xavier Pujol Gebellí 17/04/2004
ep06	Cáncer, ¿una guerra perdida? Lola Galán 06/06/2004

ep11 Un principio activo del 'cannabis' impide el riego sanguíneo de tumores. Emilio de Benito 17/08/2004

ep13 "El cáncer de mama dejará de ser causa de muerte y lo vamos a ver nosotros". Milagros P. Oliva 19/10/2004

ep16 Un grupo español crea un nuevo 'super-ratón' resistente al cáncer. Javier Sampedro 03/11/2004

ep17 Un nuevo fármaco frena el mieloma en el 35% de pacientes desahuciados. Emilio de Benito 19/02/2005

ep34 Los genes del cáncer muestran sus secretos. Gina Kolata 21/02/2006

ep51 Moléculas artificiales para bloquear la metástasis del cáncer. June Fernández 15/07/07

ep52 Una molécula para que el cáncer se 'suicide'. Mónica L. Ferraldo 21/07/2007

ep55 En busca de una teoría del cáncer. Mónica Salomone 10/10/2007

ep59 Un nuevo gen para frenar el cáncer. Ester Riu 26/02/2008

ep68 Identificado el mecanismo que permite a las células sobrevivir a la quimioterapia. EFE 05/01/2009

ep71 Una terapia destruye los melanomas "desde dentro". Emilio de Benito 04/08/2009

ep73 Ataque español al melanoma. Emilio de Benito 24/08/2009

El Mundo

em03 Probada la utilidad de un fármaco contra el cáncer avanzado de próstata. Javier Marco 07/10/2004

em05 Descubierto un gen clave en la formación de tumores. María Valerio 08/02/2005

em13 Descrito un mecanismo natural para frenar el proceso tumoral. María Valerio 03/08/2005

em19 Un retrovitus puede actuar como cofactor del cáncer prostático. Isabel Perancho 01/04/2006

em26 Dos estudios en ratones logran modular un gen clave para frenar el crecimiento tumoral. María Valerio 24/01/2007

em37 Un microchip permite 'cazar' células cancerosas en un test sanguíneo. María Valerio 21/12/2007

em59 ¿Cómo matar de hambre al tumor? María Valerio 11/03/2009

em56 El 'séptimo jinete' del cáncer. Ángeles López 02/01/2009

em61 Marihuana contra las células cancerosas. María Valerio 02/04/2009

em63 Fármacos ya conocidos funcionan para frenar las metástasis del cáncer. María Valerio 17/06/2009

em65 Nace una nueva familia de fármacos contra el cáncer de mama. María Valerio 25/06/2009

em67 Científicos españoles logran que las células del melanoma se 'autodevoren'. María Valerio 03/08/2009

em68 La UIB descubre un nuevo fármaco contra el cáncer. 04/08/2009

em69	'Hay que ir hacia una terapia personalizada contra el cáncer'. Miguel Pradas 04/08/2009
em70	Cinco estudios hallan el vínculo que relaciona las células madre con el cáncer. Cristina de Martos 10/08/2009

CHAPTER 6

Non-verbal and multimodal metaphors bring biology into the picture

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The relationship between multimodality and cognitive effects has become an important topic of discussion in Cognitive Linguistics. A growing number of studies explore the multimodal manifestations of figurative thought in a wide range of domains. However, little research has been done on visual and auditory metaphor in science. This chapter examines (i) pictures from a corpus of publications covering different biology subdomains and (ii) video clips that feature animals and biological processes. The corpus includes expert material and popular science resources. Empirical evidence is provided that visuals, non-verbal sounds, and words work either separately or together to construe metaphors, which have a major role in building scientific theories in biology and in communicating these theories to laypeople and learners.

Keywords: nonverbal and multimodal metaphor, biology, expert and non-expert communication, resemblance and non-resemblance metaphors, productivity, effectiveness

1. Introduction

Academic research in the humanities has shifted from a focus on exclusively verbal text to discourses in which language is but one communicative mode (Forceville & Uríos-Aparisi, 2009, p. 3). In Cognitive Linguistics, this change of perspective has resulted in a wide range of studies that account for the nature of non-verbal and multimodal perception, including pictorial and written signs, spoken signs, gestures, nonverbal sounds, music, smell, taste, and touch.

Importantly, current research addresses the interplay of nonlinguistic modes and figurative thought for meaning creation in different domains. For example, Forceville (1996) contributes to visual metaphor description by discussing pictorial metaphors in advertising. Zbikowski (2009) analyses the musical mode of

https://doi.org/10.1075/ftl.6.06gom

conceptual metaphors and Caballero (2009) studies the interaction of audio and visual devices in winespeak. The interest in semiotic modes other than text has even inspired research on image schemas, involving less studied senses, such as touch (Popova, 2005). Research has shown that image schemas are frequently the anchor of conceptual metaphor (Hampe, 2005; Gibbs & Colston, 2006).

Although multimodality *and* figurative thought have been documented in a wide range of domains of experience, their interaction in scientific communication has been rarely explored. One of the few scholars who have addressed this matter is Núñez (2008), who examines the domain of mathematics to show that gestures by lecturers on the topic supplement textual evidence of metaphoric conceptualisation. However, the great majority of authors who have studied metaphor both in expert discourse and science pedagogy (e.g. Brown, 2003 in chemistry; Temmerman, 2000, 2008 in genetics; Cameron, 2003 in mathematics, *inter alia*; Ureña & Faber, 2010 and Ureña, Faber, and Buendía, 2013 in marine biology) focus on the prototypical verbal monomode to describe the semantic and conceptual underpinnings of metaphor.

Based on authentic (printed and filmed) materials, this study shows that non-linguistic metaphors (i.e. visuals and sound/music) not only figure prominently in scientific communication, but they also interact in order to convey meaning and inform as well as attract the audience. The corpus includes (i) pictures extracted from a set of publications dealing with a variety of biology subdomains and (ii) video clips from documentaries that feature animals and biological processes. The publications that include the pictures are 15 research articles from academic journals and 10 proceedings from conferences on biology. A total of 15 video clips from documentaries have been collected for analysis in this study. All these materials were selected to become a part of the corpus because they are representative of how pictures and videos are exploited in science making and science pedagogy. In other words, these visual materials were chosen because they clearly illustrate the cognitive and semiotic potential of non-verbal and multimodal metaphor for both pedagogical and theory-constitutive purposes in natural sciences. This paper is thus in line with the work by textual metaphor scholars, such as Knudsen (2003), who show that metaphor not only guides scientific observations as well as the development of theories and hypothesis, but is also instrumental to science pedagogy. This claim was originally made by well-known philosophers of science, such as Hesse (1974, 1993) and Boyd (1993).

2. Objectives of the study

Cognitivist metaphor research is in need of rigorous analysis of the role of non-verbal and multimodal metaphors in subject-oriented discourse and specialised knowledge fields. This study focuses on this type of metaphor in biology, putting its significance to the test in both expert-to-expert and expert-to-learner/layperson communicative situations. The following objectives and hypotheses are established:

1. In relation to (1.), in what ways are nonverbal and multimodal theory-constitutive metaphors in the corpus found to be generative in the sense of guiding scientists' actual thinking about the phenomena under study by suggesting hypotheses, and structuring observations? In what ways are nonverbal and multimodal pedagogical metaphors effective, inferential and attractive to explain and illustrate specialised concepts to a nonprofessional audience? In other words, to what extent are nonverbal and multimodal biology metaphors productive with a rich or highly focused inference structure?
2. Are exceptions identified where a nonverbal or multimodal metaphor does not convey meaning usefully, does not map accurately or is misleading? Are such exceptions used pedagogically?
3. Are nonverbal and multimodal biology metaphors largely conventional or idiosyncratic? This highlights the need to examine their degree of entrenchment.
4. Can the dichotomy resemblance metaphor vs. non-resemblance metaphor in scientific terminology (Ureña & Faber, 2010) – that is, specialised language – be easily identified in nonverbal biology metaphors?
5. In what sense can nonverbal and multimodal metaphors make certain aspects of conceptual metaphors salient, which are not, or not as clearly, expressible in their verbal manifestations? (Forceville & Uríos-Aparisi, 2009, p. 13).

To answer these questions, this research is divided into sections and subsections which focus on the specific monomodality or multimodality and the type of mode(s) operating.

3. Monomodality

Differentiating monomodality and multimodality is necessary to effectively conduct a practical analysis of biology metaphors. As Forceville (2009, p. 23) points out, the target and source in a monomodal metaphor are exclusively or predominantly rendered in one mode. In contrast, multimodal metaphors are more complex in nature, emerging from different modes of representation (see Section 4).

One type of monomodal metaphor that has become central to multimodal studies is pictorial or visual metaphor. This section provides evidence that visual metaphor is widely used in the field of biology both to create and structure science and to explain scientific concepts to laypeople. Visuals can be broadly divided into static images (pictures) and dynamic images (movement in body postures).

3.1 Static images: Pictures

Expert science materials were originally thought to only include pictorial representations free of figurative devices since it was generally accepted that they should be clear, straightforward, and precise. Evidence is given in this study that static visuals used by biologists in academic publications (e.g. pictures, drawings, and graphical material) can also have a metaphorical basis to convey science.

3.1.1 *Tree metaphors*

The picture in Figure 1 was on a poster of the Second International Conference of Eugenics in 1921. Eugenics is concerned with the hereditary improvement of the human race by selective breeding. The figure depicts this academic field, which was new at that time, as a tree fed by roots from a variety of disciplines (genetics, biology, sociology, etc.). The aim of the author is to illustrate the eclectic nature of eugenics, which draws on a wide range of (closely) related fields, by means of the metaphors EUGENICS IS A TREE and DISCIPLINES ARE TREE ROOTS. These metaphors allow the author to organise all these disciplines into a harmonious superorganism.

These tree metaphors fall into the category of *conceptual metaphor* in Lakoff's (e.g. 1993) Conceptual Metaphor Theory. Unlike resemblance metaphors (Grady, 1999), which emerge from physical (shape and/or colour and/or size) or behavioural comparison between source and target as material entities, conceptual metaphors rather arise from complex, abstract structure. As Lakoff (1993, p. 229) notes, in conceptual metaphors abstract concepts are understood in terms of concrete concepts directly grounded in bodily (sensorimotor) experience.

On this basis, disciplines – abstract entities – are metaphorically conceptualised as trees and tree parts, which are concrete objects. The arrangement of the disciplines looks like the configuration of a tree with roots, trunk, branches, and leaves. The disciplines that eugenics stems from are represented by the roots, whose function is to feed and support eugenics. Thus, the specific conceptual metaphor disciplines supplementing eugenics are the roots of a tree can be formulated. Eugenics is visually rendered by the trunk, branches, and leaves of the

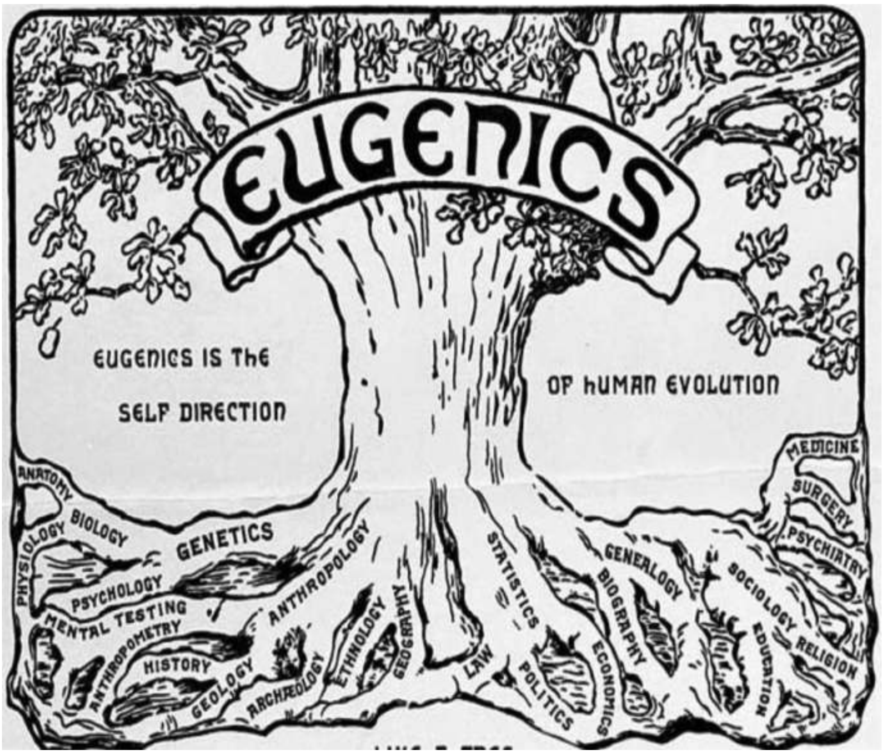


Figure 1. Eugenics as a tree fed by roots from a variety of disciplines

tree. Thus, we can establish the specific conceptual metaphor EUGENICS IS THE TRUNK, BRANCHES AND LEAVES OF A TREE. It should be noted that although the branches and leaves are pictorially represented in the figure, they are not explicitly differentiated as metaphoric sub-mappings. In any case, it can be interpreted, the picture includes a good number of branches and leaves because they are intended to express the idea that eugenics is a multi-faceted discipline with many applications and the power to yield a good deal of positive results to humanity. Therefore, EACH BRANCH (source) could be metaphorically understood as ONE APPLICATION (target) and EACH LEAF (source) ONE POSITIVE RESULT (target).

Interestingly, Figure 1 also includes three primary metaphors, which emerge from the correlation (*conflation*) between two events that repeatedly co-occur in experience (Grady, 1997; Lakoff & Johnson, 1999, p. 49). This embodied aspect of primary metaphors is specifically discussed in Subsections 3.1.2 and 3.2.1. The first primary metaphor, IMPORTANT IS SUPERFICIAL AND PROXIMAL, is my suggestion and a derivation of IMPORTANT IS CENTRAL, provided by Grady (see 3.1.2). IMPORTANT IS SUPERFICIAL AND PROXIMAL is represented in Figure 1 by the fact that essential disciplines to eugenics, such as genetics, statistics and genealogy, are in very close proximity to the ground and/or to the above-ground part of the tree, which represents eugenics. In contrast, the second primary metaphor, ACCESSORY IS DEEP AND REMOTE (also a derivation of IMPORTANT IS CENTRAL), involves disciplines that have less in common with, and thus, are less relevant to eugenics. This is the reason why disciplines such as geology and religion appear as roots furthest down from the trunk.

The third primary metaphor in Figure 1, IMPORTANT IS BIG, which appears in the list of Grady's primary metaphors included in Lakoff and Johnson (1999, p. 50). This metaphor has a pictorial rendering of two types. Both types explain that eugenics is the most relevant discipline in the drawing. Firstly, the importance of eugenics is visually represented by the trunk, whose diameter is significantly larger than that of the roots, representing the rest of disciplines as subordinated fields. Secondly, the metaphor concerns the size of the word *eugenics*, which is written in big capital letters. On closer examination, the degree of importance of all disciplines in the tree is signalled by the size of their fonts. Based on this criterion, the author of the picture establishes three levels of importance: (i) eugenics, (ii) genetics, and (iii) the rest of disciplines. There are examples in the picture where this degree of significance and dependence between disciplines is further narrowed down visually by means of the IMPORTANT IS BIG metaphor. The level of subsidiarity is expressed in the figure taking the width of the roots as a reference. This is the case for the genetics-psychology-biology-anatomy-physiology cluster on the left bottom side of the figure. A bigger root, representing genetics, derives to two subsidiary – and thus, smaller or narrower – sub-roots, representing psychology and biology. In turn, biology feeds on anatomy and physiology, represented in the picture as the narrowest roots in the hierarchy.

All of these pictorial metaphors are complemented in Figure 1 by the conceptual metaphor EUGENICS IS THE SELF-DIRECTION OF HUMAN EVOLUTION,[1] which is linguistically expressed. Being grounded in the sensorimotor experience of seeing an object in motion and following a well-defined pathway in space, this metaphor conceptualises eugenics as a self-contained, autonomous scientific field with the capacity to direct its own way (self-directed). This metaphor is on a par with the LOVE IS A JOURNEY metaphor, firstly suggested by Lakoff and Johnson (1980, p. 45), since both of them are used to understand purely abstract concepts (EUGENICS and LOVE) as physical concepts involving movement and dynamism (SELF-DIRECTION (IN A PATH) and JOURNEY). Even though the visual tree metaphors discussed above and the verbal metaphor EUGENICS IS THE SELF-DIRECTION OF HUMAN EVOLUTION

1. What actually serves as the source of the conceptual metaphor is SELF-DIRECTION, which is a physical and embodied element (as explained in the body text). There is thus one metaphor (HUMAN EVOLUTION IS A CONCRETE ENTITY WITH SELF-DIRECTION/THAT MOVES FORWARD) within another metaphor (EUGENICS IS THE SELF-DIRECTION OF HUMAN EVOLUTION). In addition, and as a consequence, there is one metonymy, where EUGENICS (the part) stands for HUMAN EVOLUTION (the whole). For practical purposes, in the body text I only elaborate on the assumption that eugenics is conceptualised as a concrete entity with the capacity for self-direction.

are essentially different in nature, all of them go to reinforce the claim that eugenics is a self-standing discipline that is central and indispensable to human thriving and development.

The tree metaphor is a clear example of how to use basic models in science for the effective arrangement and presentation of typologies. In fact, this metaphor is extensively used across the full spectrum of scientific disciplines – particularly widely exploited in biology and natural evolution theories (Gruber, 2005, p. 245) – and can thus be regarded as conventional and well-entrenched. This pictorial metaphor usually undergoes a process of simplification whereby the content-rich tree-shape representation of biological results is abstracted into schematic structures, which are easily recognisable because of the metaphor's high degree of conventionality. An instance of schematisation due to entrenchment is the metaphor TAXONOMIES ARE TREES, depicted in Figure 2, which was extracted from a research article in an academic journal (cf. Medina, Jones & Fitzpatrick, 2011). The trunk, branches, and leaves of this tree have been abstracted into simple straight lines (the length and width of the trunk have even been kept to a minimum). This perceptual process is cognitively transformed into a *gestalt* (Lakoff & Johnson, 1980, p. 70), which keeps the structure stable by foregrounding the whole to the detriment of the parts.

For fungus taxonomic reconstruction, TAXONOMIES ARE TREES dispenses with the roots, downplays the trunk, and focuses on the branches (e.g. Chytriomycota) and leaves (e.g. *Allomyces macrogynus*). The possibility of zooming in on different parts of the tree to refer to biological concepts enhances the productivity and inference structure of the tree metaphor, which contributes to the advance of biological sciences. At any rate, the metaphor in Figure 2 is a conceptual metaphor for the same reason as the one that applies to the visual metaphors in Figure 1, that is, abstract concepts are understood in terms of concrete concepts that are directly grounded in bodily (sensorimotor) experience. In this case, the concrete-to-abstract metaphoric mappings involve the concrete source concepts TREE BRANCHES and LEAVES being mapped onto the abstract target concepts PHYLUM, SUBPHYLUM, CLASS, SUBCLASS and SPECIES, which are categories making up the hierarchical structure of biological kingdoms. By virtue of the tree metaphor, these abstract entities are conceptualised as, and visually organised into, an arboreal arrangement.

The phylum (Basidiomycota) in question as well as each specific subphylum (e.g. Agaricomycotina), class (e.g. Homobasidiomycetes), subclass (e.g. Agaricomycetidae) and species (e.g. *Laccaria bicolor*) take a particular position on the tree hierarchy. Specifically, all fungal categories in the arboreal structure are metaphorically understood as branches, except for the species, which are conceptualised as leaves because they have been placed on top of the tree. However, it is the positions (abstract concepts) and not the fungi proper (concrete entities)

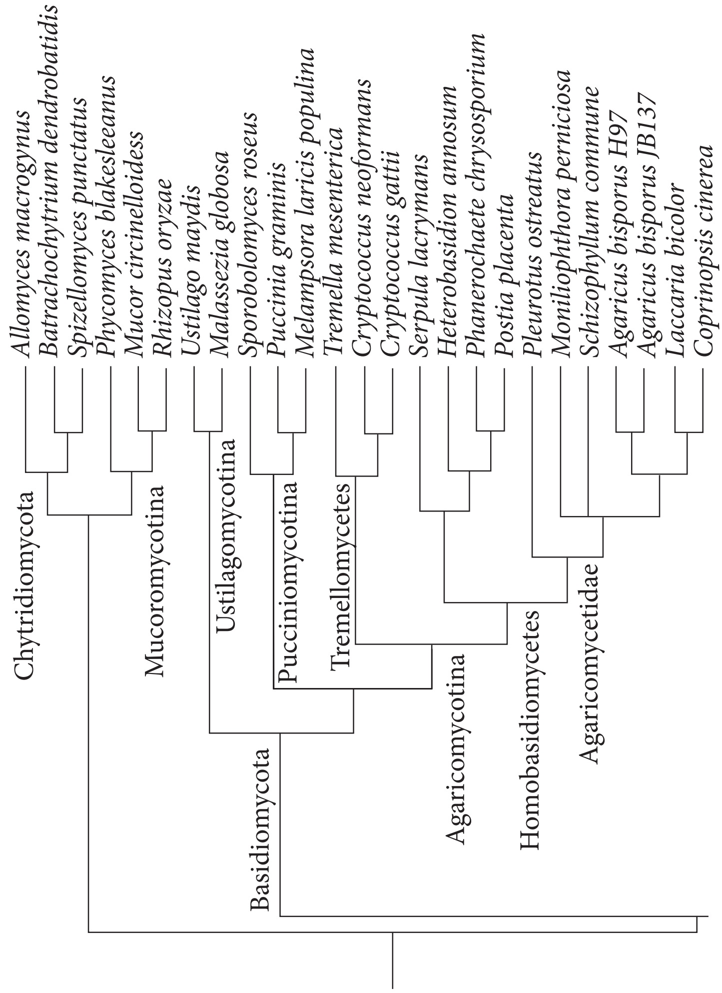


Figure 2. Cladogram of the fungal tree of life (detail)

that actually participate in the cross-domain mappings. In other words, it is not that the physical features of fungi in the taxonomic structure are compared with the physical features of tree branches and leaves (if this were the case, we would be speaking of a resemblance metaphor). Instead, it is the hierarchical locations of the fungi in the cladogram that are compared with the positions of the branches and leaves in a tree. For this reason, it is a conceptual metaphor that is operating here.

As can be observed, the authors of the article use the tree metaphor to *re*organise and *re*construct fungus taxons. As they point out, "this is the first time multigene families have been used in fungal supertree reconstruction and permits us to use up to 66% of the 1,001,217 genes in our fungal database" (Medina et al., 2011, p. 116). This clearly indicates that the tree metaphor is theory-constitutive insofar as it forms an intrinsic part of the mental and visual model that scientists rely on to classify living beings and organise them into taxonomic hierarchies. Importantly, this metaphor helps to further scientific research in the study of fungi. Furthermore this metaphor was probably applied to the visual taxonomic *re*organisation of multi-gene fungal families even before it was well-supported empirically, which reinforces the effectiveness of the metaphor and makes it even more commonplace. Instances of metaphors that guide investigation before empirical postulation can also be found in figurative terms, as is the case of *DNA barcoding*, suggested by Hebert prior to the broad acceptance and validation of this phenomenon by the scientific community (Larson, 2009, p. 173).

3.1.2 *Other pictorial metaphors*

Self-contained visual metaphors can also work together for scientific knowledge representation and transfer. Figure 3, extracted from an academic journal article, explains the interaction between two wind drifts crucial for specific sea organisms such as white sharks. The picture builds on at least six visual metaphors.

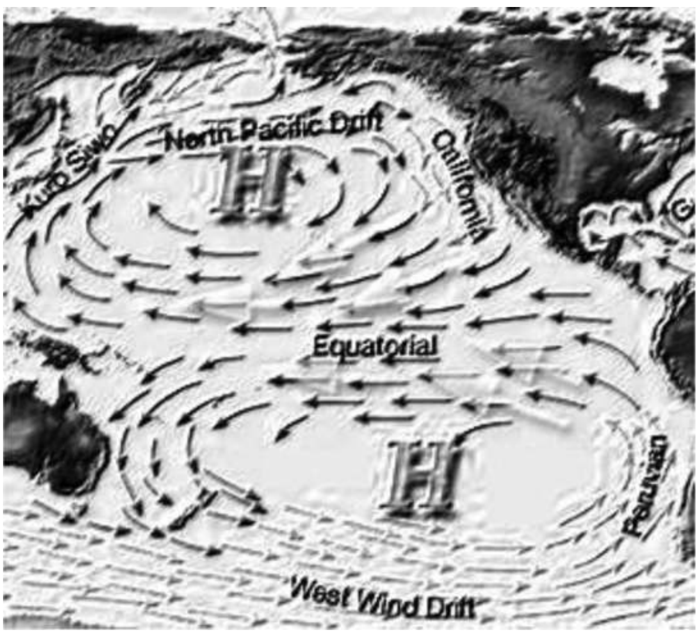


Figure 3. Pictorial metaphors explaining wind drift interactions

The first two metaphors involve the letter *H*, which stands for *high pressure*. *H* is placed at the centre of the wind drifts on the map to visually highlight its importance, since high pressure is a major cause for certain winds to occur. Although the *H* might have been placed on the left or right, the metaphor IMPORTANT IS CENTRAL is operating here. The prominent size of *H* reinforces this by introducing the metaphor IMPORTANT IS BIG. Both IMPORTANT IS BIG and IMPORTANT IS CENTRAL are conventional metaphors and are commonly instantiated diagrammatically by scientists to rapidly structure and convey scientific knowledge, as also shown by the tree metaphor in Section 3.1.1.

Another metaphor included in Figure 3 is MOTION IS LINES/ARROWS. In the picture, the arrows stand for forces/entities in motion, expressing concretely how the wind drifts (black and grey arrows) and white sharks move (white arrows). This metaphor is grounded in our embodied experience of a moving entity/force brushing our bodies or cutting through the air. Movement in space and velocity imply physical projection/expansion and is typically depicted as an elongated line or arrow in scientific disciplines. For instance, Watson, Spyrou and Tall (2003, pp. 74, 78) explain that the reason why arrows are used as visual representations of vectors in mathematics lies in physical embodiment. The dynamicity of the arrows in Figure 3 is evident, even though it is constrained by the mode of representation, which is static. Compare this with visual metaphors depicted by real movement in video clips (see 3.2).

Colours also play a major role in the figurative representation of biological and atmospheric patterns. In the original diagram that Figure 3 is based upon, the black and grey arrows are in reality red and blue, thus standing for warm and cold currents, respectively. This colour distinction helps the reader of the article to easily identify the nature of the winds on the map. The underlying metaphors, COLD IS BLUE and HOT IS RED, have an embodied grounding as well. Firstly, the associations *cold-blue* and *hot-red* are made based on our perception of the colours of fire and ice (partly red and somewhat white-blue, respectively), which are physical features sensed by sight. Secondly, these associations also arise from the visual appearance of the physiological response to cold and hot temperatures seen most clearly in light-skinned human beings; when it is very cold, lips and nails become a bluish purple, and when it is very hot, the skin turns red. The explanation for this is that cold constricts blood vessels, so blood is less visible to the naked eye, whereas heat dilates them, which facilitates blood circulation.

Therefore, COLD IS BLUE and HOT IS RED can be regarded as primary metaphors since they involve conflation or repeated co-occurrences of phenomena in bodily experience. As a matter of fact, it has been shown that instinctive and basic body patterns that give rise to metaphoric thought are intrinsically associated with *experiential correlation* (Grady, 1997, pp. 47–48), an inherent aspect of primary metaphors which consists of establishing a strong conceptual link between two distinct events that repeatedly co-occur. This phenomenon usually gives rise to cause-effect correlation metaphors because after repeated co-occurrences, in experience of the world, we come to conceive one event in terms of another. This structure has also been found in the metaphoric nature of marine biology terminology (cf. Ureña & Faber, 2010). Finally, the white arrows in Figure 3 stand for the white sharks, which normally follow warm currents over cold one. This is so because in contrast to most fish, which are cold-blooded, the white shark is warm-blooded, and can regulate its body temperature (Goldman, 1997, p. 423). Correspondingly, arrows are mapped onto shark movement and sharks themselves, forming a PART FOR THE WHOLE metonymy, specifically WHITE COLOUR FOR WHITE SHARK.

All these figurative devices help experts explain a scientific finding to their peers by giving cognitive and visual structure to its representation. The use of arrows and the pairs *cold-blue* and *hot-red* is so effective and productive that they are found in many other technico-scientific fields. For instance, in the specialised subdomain of thermal engineering, air circulation during gas combustion in direct-vent fireplaces is depicted in the form of blue arrows, standing for motion of outdoor unheated/cold air, and red arrows, standing for motion of indoor heated/hot air.

All the previously discussed metaphors, including the concepts *wind drift*, *importance*, *temperature* (*cold* and *hot*), *pressure*, *arrow*, and *direction*, intermingle to give rise to the compound conceptual metaphor FLOW AND TEMPERATURE ARE ARROWS AND RED/BLUE COLOURS. Having the function of structuring and transmitting specialised knowledge, this metaphor underlies the cognitive context of many academic subject-oriented papers, running the gamut from purely scientific (e.g. biology) to more technical (e.g. engineering) knowledge domains, as has been demonstrated.

Figure 4, extracted from an article in a Spanish-language academic journal, is an example of how widely the metaphorical representation of FLOW is used in pictorial resources of biology research. The figure illustrates the *life cycle* of *Durvillaea antarctica*, a sea alga species. Arrows and circulation are crucial to describe a biological process through a pictorial metaphor. This time, the metaphorical frame is different from the ones discussed above because the arrows in Figure 4 do not indicate motion of a physical force (e.g. a wind drift) in space, but the developmental stages of the alga in time. The underlying metaphor is TIME IS SPACE, which has been discussed in detail in cognitive-linguistics studies (e.g. Lakoff & Johnson, 1999; Evans, 2013). In the literature, this is known as *the Moving Time metaphor* (Evans, 2013, p. 164). Again, an abstract concept (TIME) is conceptualised as a concrete one (SPACE). Specifically, Figure 4 builds upon the sub-metaphor TEMPORAL SEQUENCE IS SPATIAL POSITION ON A LINEAR PATH (Moore, 2006), where the transience of the different stages of algae to becoming reproductive adult plants (target) is depicted as moving arrows at different positions in space (source) in the picture.

It is the phylogenic (i.e. evolutionary development and history of a particular species) *cycle* of an organism that is visually represented, which means that this process is *repeated* uninterruptedly across individuals in the same species as they are born and die. For this reason, the timeline featuring such a process is represented not by straight but by curved arrows tracing a closing circle.

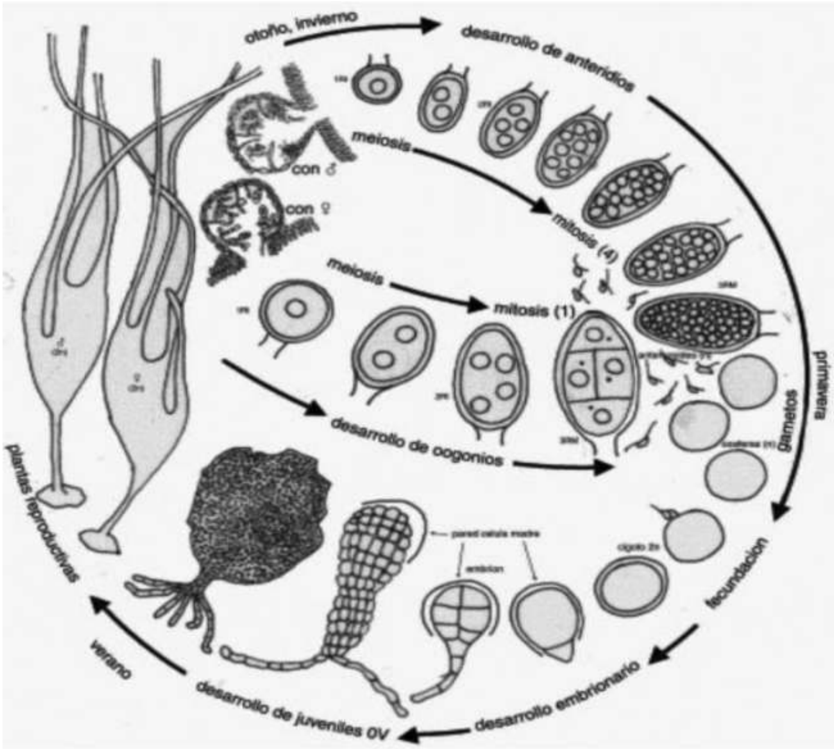


Figure 4. Life history of the alga *Durvillaea Antarctica*

3.1.3 *Summary of contents*

This section has given empirical evidence that conceptual metaphors involving TREE, ARROW, BLUE AND RED, and CIRCLE as source domains are commonplace in the scientific knowledge field. These metaphors are particularly habitual in natural sciences research studies, where they operate to present biological entities and processes through pictorial devices. The TREE, ARROW, BLUE AND RED, and CIRCLE metaphors are non-resemblance in nature, which makes evident how useful they are to visually express abstract concepts through pictorial resources in expert-to-expert communication. This reinforces the value of metaphoric thought and conventional visual metaphors in specialised circles.

Being non-resemblance metaphors, the pictorial tree metaphors are effective in visually representing and organising abstract aspects or dimensions, such as, in examples given above, the degree of significance and embedment of a set of branches of knowledge with respect to a certain discipline and the fine-grained arrangement of fungi into taxonomic categories. The tree metaphors are also highly generative, irrespective of their level of abstraction: despite lacking leaves and roots and having highly schematic branches, the fungi tree may be judged as effective and inferential as the discipline tree, with its well-defined branches and roots. Interestingly, the tree metaphors discussed emerge from a number of primary metaphors, which are directly anchored in our sensorimotor experience, where two events always co-occur on a cause-effect basis.

The FLOW conceptual metaphor divides into two types of target-source mappings: FLOW-TEMPERATURE conceptualised as ARROWS-BLUE/RED COLOURS (e.g. wind drift interactions) and FLOW-TIME conceptualised as STRAIGHT/CURVED ARROWS (e.g. developmental stages of the *Durvillaea Antarctica* alga). As explained above, the pairs *cold-blue* and *hot-red*, being a part of the circulation/flow schema, are mapped from physiological and perceptual bodily experience, and subsequently from features of the environment. As a whole, the depiction of both types of conceptual mappings crucially assists biologists in presenting their peers with specialised concepts and phenomena in academic papers. We can thus conclude that the metaphor vehicles ARROWS and RED/BLUE COLOURS are sufficiently inferential to guide scientific investigation.

Despite their success in explaining science, static images are less effective in featuring and exploiting conceptual metaphors. The next section turns to visual metaphors found in *dynamic* images featuring different animals, and highlights the value of these images to get scholars' messages across not only to other specialists in academic communicative situations, but also to non-experts in pedagogical environments.

3.2 Dynamic images: Animal body language

The figurative grounding of human gestures and body postures is currently widely discussed (e.g. Cienki & Müller, 2010). Nevertheless, little has been written about the metaphoricity of zoosemiosis – i.e. communication within and across non-human animal species – from a cognitive-linguistic point of view. Evidence is provided in this paper that animal physical signification, representation, and communication, the three pillars of zoosemiosis (Martinelli, 2010, p. 1), can be figuratively interpreted. As will be explained, the application of metaphoric structure to the animal world raises interesting questions among expert biologists and cognitive psychologists, and has positive implications for non-specialist readers' understanding and consolidation of specialised knowledge and for their amusement in learning.

3.2.1 *The Brazilian wandering spider*

A good example of the metaphoricity of animal body language is the characteristic threatening position and movement that the poisonous Brazilian wandering spider (genus *Phoneutria*) adopts to scare away potential predators. Expert documents provide evidence of this behaviour. Specifically, the spider's body posture is illustrated in Figure 5, and described by biologists Martins & Bertani (2007, p. 1), who write that for this defensive display the spider holds its frontal legs high after lifting its body to an erect position, and performs swinging lateral movements. Unfortunately, no video clips could be retrieved from specialised sources to show this movement. Nonetheless, this dynamic behavioural pattern is clearly evident in the Youtube® video clip at http://www.youtube.com/watch?v=-zfzY14l23g.

Figure 5. Threatening posture of the Brazilian wandering spider

From a cognitivist perspective, two primary metaphors can be argued to emerge from this instance of kinaesthetic or body language. As is well known, the embodiment approach to metaphor (Lakoff & Johnson, 1999) sees kinaesthetics as the foundation of basic, primary metaphoric models that are acquired early in life by means of conflation/co-occurrence of two events (see examples of experiential correlation in 3.1.2 and below in this section). The first primary metaphor, CONTROL/POWER IS UP, builds on the spider's erect position and lifted frontal legs, which expose its venom-loaded fangs. In regards to humans, psycholinguistic research (Schubert, 2005) shows that the concepts of power, dominance, and status are partially mapped onto the physical vertical dimension, which implies that the metaphors LACK OF CONTROL IS DOWN and CONTROL IS UP are embodied. Linguistically speaking, these metaphors are reflected in sentences such as *He is at the bottom of the social hierarchy; His power is on the decline; I am on top of the situation*; and *I have control over Paul, so he will do whatever I order him*.

These paradigms can be applied to the wandering spider from a cognitivist *human* perspective. Applying humans' responses to danger, it can be interpreted that this animal is attempting to gain an up-high vantage point, which should intimidate its opponent and give the spider a sense of superiority over it. It is quite the same effect made by cobra snakes when they raise their bodies upright if threatened. An example of the reverse interpretation involves a dog crouching its body low and putting its ears and tail down to show submission to a stronger conspecific or to any other more powerful animal. The fact that a primary metaphor is rooted in the spider's body posture is hardly a coincidence. Specifically, again, we can speak of a visual primary metaphor, which is thus grounded in experiential correlation (cause-effect structure). Accordingly, it may be interpreted that by *raising* its body and legs (cause), the wandering spider has learnt to gain a physical, and eventually, psychological advantage over its enemies (effect). In the metaphor, the source UP is mapped onto the target CONTROL/DOMINANCE. This conceptual pattern evidently makes correlation metaphors, one type of non-resemblance metaphor, different from resemblance metaphors, which emerge from physical appearance and/or behavioural comparison.

Specifically, the CONTROL IS UP metaphor complies with Grady's (1997) central claim about primary metaphors. According to this claim, the distinction between target and the source in primary metaphors is the *degree of subjectivity* rather than how clearly delineated or how abstract the target concept is (Evans & Green, 2006, p. 304). On this basis, CONTROL, a subjective (difficult to measure or quantify) concept, is understood in terms of UP, an objectively measurable perceptible unit.

In any case, visual metaphors of this type can also support Conceptual Metaphor Theory's (e.g. Lakoff & Johnson, 1980; Lakoff, 1993) major tenet that conceptual metaphor facilitates for scholars and students the understanding of abstract concepts (psychological advantage) in terms of concrete ones (rise of the body). In fact, what the spider makes is an *abstract referential gesture,*[2] which contrasts with an *iconic gesture* (cf. Cienki & Müller, 2010). In the abstract referential gesture, the abstract referent itself cannot be represented iconically since what is being referred to lacks a physical structure that can inherently be depicted with the limbs. In our case, dominance is an abstract concept/referent that fails to have perceptual properties. Consequently, this type of gestural sign corresponds to the non-resemblance metaphor category. An example of iconic gesture in biology involves the dark-footed ant spider (*Myrmarachne melanotarsa*), which purposely stretches its frontal legs forwards and horizontally, in an unnatural position, in order to mimic the antennae of a real ant (Figure 6). This spider species bears a stunning resemblance to an ant *per se*, but the leg stretching performance enhances the ant imitation model even further.

Leg-stretching is a defence strategy against ant-averse predators and as a camouflage technique to go unnoticed, which enables the spider to gain access to and eat the eggs of other spider species (Nelson & Jackson, 2009). From an

2. Although they are intrinsically linked to human communication, gestures should be broadly understood in this context as part of the more general category of kinesthetics, i.e. the movement of the body in three-dimensional space (Koller, 2009, p. 64).

Figure 6. An ant-looking spider enhances impersonation by stretching its frontal legs forwards, so that they look like an ant's antennae.

anthropocentric point of view, this gesture constitutes a visual resemblance metaphor, which involves concrete-to-concrete mappings between two entities (i.e. the spider and an ant), based on physical comparison. As can be seen, the use of visual metaphors can be extremely useful to consolidate the knowledge of learners of biology about particular behavioural patterns and specific physical features of species. In other words, establishing stimulating and amusing comparisons between different animal categories draws students' attention, which may help them better remember details of the survival strategies of a particular species. This strategy is thus an aid to memory.

The second primary metaphor is CONTROL IS (SWAYING) MOVEMENT. Again, the wandering spider sways its body sideways (cause) to gain a physical vantage point and intimidate its enemy (effect), which ultimately enables the spider to take control of the situation. This behaviour is like a boxer's, who tries to gain control and expresses intimidation by swaying from side to side before his opponent to confuse his attack and finally find a good angle to punch him. The conceptual metaphor SPIDER BEHAVIOUR IS BOXER BEHAVIOUR can thus be formulated. Not surprisingly, the metaphor CONTROL IS (SWAYING) MOVEMENT has a clear linguistic correlation in Spanish expressions such as *Deja de vacilarme!* [Stop teasing/intimidating me!], where *vacilar* literally means *to sway*.

Let us elaborate on why it is worth using the spider metaphors to build scientific theories on animal behaviour and cognition or to bring specialised concepts to learners. If we ask ourselves under what circumstances a nonverbal or multimodal metaphor can be construed, the answer in this case is that the spider metaphors may help biologists make structuring inferences, resulting in comparing, contrasting, identifying, and classifying differing animal species, as well as in forming hypothesis about the biology and ecology of such species. In addition, these metaphors provide evidence to cognitive linguists that embodied cognition is also applicable to animal description, which expands the applicability of metaphor studies to other knowledge fields. These metaphors also assist cognitivists in describing primary, and thus highly instinctive and hard to identify, cognitive mechanisms in zoosemiotics.

Importantly, applying the spider metaphors to the animal world also brings up the question of the existence of metaphoric thinking in non-human animals. This thought-provoking hypothesis concerns ethologists, cognitive semioticians in cross-species studies, and experts in animal cognitive psychology. Suggesting that the conception of mental events in animal cognition is rooted in conceptual metaphors is currently too challenging. However, once demonstrated that specific brain structures are activated during metaphoric processing in humans (Rapp, Leube, Erb, Grodd & Kircher, 2004), neurobiological experimentation in animals could be initiated in this direction. In fact, there is a burgeoning strand of zoosemiotics, known as *the pluralistic view of zoosemiotics* (e.g. Martinelli, 2010, 2011; Maran, Martinelli & Turovski, 2011; Ureña, 2014), which leaves the door open for the existence of sophisticated mental life and superior psychic faculties in non-human species (Maran et al., 2011, p. 14). This is known as *comparative anthropological zoosemiotics*, which makes comparisons between human and non-human semiosis with a view to establishing potential connections between the two codes (Maran et al., 2011, p. 9). Ureña (2014), for example, applies image schemas, which are fundamental constructs of human cognitive psychology and (applied) cognitive linguistics, to the complex and potentially reflective behaviour of the mimic octopus (*Thaumoctopus mimicus*) when it engages in imitation of other sea organisms, such as a flatfish and a lionfish, for survival purposes.

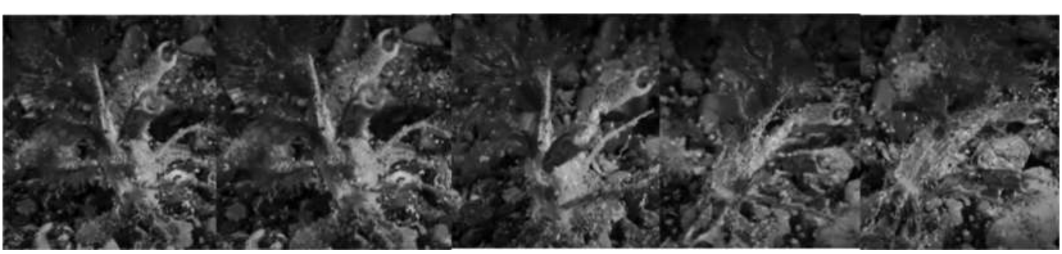
Describing and illustrating the Brazilian wandering spider metaphors with the visual support of video clips is also useful to biology learners in a classroom and to laypeople in any other pedagogical environments. These metaphors assist in:

i. making explanations of animal behaviour and cognition more appealing and amusing to the non-specialist audience since premises of cognitive psychology are normally cumbersome to laypeople; this is done by mapping human psychological states (in this case, intimidation and impression) onto animal responses (in this case, very specific bodily postures and striking physical enactments) to scare antagonists off;
ii. making biology learners value the wide scope, applicability and great pedagogical potential of metaphors; in fact, they are meant to aid students' memory of specialised concepts and phenomena (e.g. the way certain species behave and interact with antagonists for survival purposes).

3.2.2 *The Gibb's sea spider*

All three dimensions of zoosemiotics (animal physical signification, representation, and communication) need not necessarily be at work at the same time. The analysis of the survival strategy of the Gibb's sea spider (*Pisa armata*), a type of crab, shows that this crustacean seems to make use of physical signification (reflective use of a semiotic sign) and representation (the way the animal would construct sense), but not of communication (interaction between the sender of the message and its receiver). I am hedging my statements because openly attributing cognitive capabilities to a lower animal is not tenable by all non-human behavioural cognitive theories. Thus, we are limiting ourselves to the cognition of human observers for the value of human metaphorical understanding. In any case, as mentioned in Section 3.2.1, these metaphors encourage ethologists, cognitive semioticians and behavioural biologist to raise hypotheses about the actual scope of animal psychic faculties and reasoning, as done by scholars in the pluralistic approach to zoosemiotics. It should also be pointed out that the analysis conducted in this subsection does not address the linguistic metaphor *sea spider*, which emerges from the physical comparison between the long and thin legs of the crab and the legs of a spider.

The documentary film sequence at http://youtu.be/sp2X-IErKrY?t=15m28s features the Gibb's sea spider. The images make explicit the metaphorical nature of the appearance and behaviour of this animal from a human perspective. Concretely, its hairy protuberances look to us like the branches of an epipelic (attached to the sediment) alga in shape and colour. In addition, the crab even seems to imitate the gentle movement of the alga (behaviour) by swaying as if at the mercy of the waves; this seems to the human observer to enable it to escape the attention of predators. So, this interpretation prompts behavioural biologists and researchers of animal cognitive psychology to ask themselves whether the *Pisa armata* draws on physical signification (to go unnoticed) and representation (to sway like an alga), while avoiding *inter*action (i.e. communication) with its predators. Figures 7–11 are stills extracted from the documentary film of the swaying movement of the crab stuck to the seabed.



Figures 7–11. Sequence depicting the alga-like appearance and swaying movement of the crab *Pisa armata*.

The figurative grounding of this physical-behavioural pattern challenges Grady's (1999) dichotomy of image metaphors vs. behaviour-based metaphors, defined as mutually exclusive, watertight categories based on motionlessness (it is the physical appearance of two entities that is compared) and dynamicity (it is the behaviour of two entities that is compared), respectively. The Gibb's sea spider's description involves a metaphor that is located in a transition zone between purely static (alga-like protuberances) and dynamic (alga-like movement) images because it emerges from both types of comparison. This was also found by Ureña & Faber (2010) when they examined the semantics of marine biology metaphorical terms, and thus, their method goes from lexis to thought – that is, they first note lexical evidence of the metaphors, and next, adduce their meaning and the underlying thought. Contrast this with the visual sequence in the documentary film of the Gibb's sea spider. The visual sequence supports Conceptual Metaphor Theory's premise (Lakoff & Johnson, 1980, p. 4) that metaphoric thought, as complex as it may be, precedes language. This is further reinforced by the fact that the metaphor-based visual characterisation of *Pisa armata* has not yet even been lexicalised by biologists or reported in their literature.

Despite its lack of lexicalisation, the figurative description of the *Pisa armata* ecology is a crucial constituent of the imagery of biologists since it helps them to identify certain biological patterns, recognise the same patterns in other animals (e.g., the orangutan crab, *Achaeus japonicus*, which has also been found to sway like algae to camouflage for survival), and finally, make species classifications. In other words, this metaphor is used to enhance theory on animal behaviour. It can thus be argued that the manipulation of visual mental images in dynamic sequences is involved in aspects of creative thought in science-making, particularly during the discovery of novel or emergent properties of living beings. It should be noted that the Gibb's sea spider metaphor started out as an idiosyncratic metaphor, and preserved this status until researchers showed this crab's behaviour to be a common pattern across crab species. At that point, the metaphor became conventional, resulting in the formulations SEA CRABS ARE ALGAE, as the generic metaphor, and SEA CRAB BEHAVIOUR IS ALGAE MOVEMENT, as the specific metaphor.

Apart from its theory-constitutive role, the Gibb's sea spider metaphor has a clear explanatory function. Once there is agreement that visuals greatly assist experts in explaining and describing specialised concepts (Fernandes, 2004), the documentary sequence shows that this also holds true for biology pedagogy. The dynamic images of the alga-like crab gently swaying immediately triggers a crab-alga comparison in the viewer's mind, who quickly learns about the survival strategy of this animal. Interestingly, at no time does the narrator make this metaphor explicit. He limits himself to describing the crab's swaying movement and to explaining its purpose (i.e. to escape the attention of possible predators), with no reference to algae as the element of comparison (in cognitivist terms, the source of the metaphor). We can thus infer that the narrator puts the viewers to the test, and assumes that they will be able to project cross-domain mappings in order to gain and consolidate knowledge.

This discourse strategy is possible because the source domain of the metaphor (ALGA) is not present in the visual, but only the target (GIBB'S SEA SPIDER) is. This is a typical aspect of real-life dynamic images involving resemblance metaphors, such as the Gibb's sea spider itself or fish imitating a loose leaf or another lifeless object that drifts side to side in the tide (cf. e.g. https://www.youtube.com/watch?v=TUgkGGIM7HY)). In contrast, in visual primary metaphors, such as those involving the Brazilian wandering spider, only the source (ERECTED BODY AND LEGS) is visible since the target (CONTROL/POWER) is abstract and more subjective in nature. Interestingly, as we will see in Section 4, the visual constituents of both the source and target of a good number of multimodal metaphors are visually represented in the video clips to enrich the metaphors and make the argumentation and explanation of biological processes and behaviours more attractive to the audience.

3.2.3 *Summary of contents*

The previous subsections make a case for studying the role of dynamic visual metaphors that underlie the behaviour of animals both in specialised and pedagogical environments. Metaphors are shown to be abundant not only in their verbal mode (in other words, in the taxonomic nomenclature of non-human species, such as *ant spider*), but also in their purely visual (and imagistic) mode to attract a non-specialist audience and for the understanding of sophisticated animal behaviour. Evidence is also given that resemblance metaphors are an often-seen type of metaphor in biology. For their realisation, they may find support in primary metaphors, which are primitive cognitive constructs that ultimately tie in sensorimotor experience with the metaphorical conceptualisation of animal enactments. This is the reason why LACK OF CONTROL IS DOWN and CONTROL IS UP, operating behind the Brazilian wandering spider metaphor, are conventional primary metaphors commonly found in the analysis of biology visuals. Because they arise from concrete-to-concrete mappings, visual resemblance metaphors are perceptually – and subsequently conceptually – more salient and identifiable than primary metaphors. Therefore, resemblance metaphors may be said to be more useful pedagogical-wise; however, primary metaphors are, on many occasions, the building blocks of resemblance ones.

From a specialised scientific perspective, dynamic visual metaphors in biology are interesting because they may prompt scholars to redress their investigation, suggesting hypothesis about animal cognitive psychology and leaving the door open for the existence of complex and reflective mental life in non-human species, along the lines of the pluralistic view of zoosemiotics. Within this framework, new research lines might emerge that sought evidence for the psychological reality of metaphoric patterns governing the behaviour of non-human animals.

In teaching and pedagogical circles, dynamic visual metaphors make the presentation of abstract concepts (such as dominance, threat and intimidation) and their intriguing connection to specific bodily responses more amusing and attractive to biology learners and laypeople interested in this scientific field. Especially effective from a pedagogical point of view is the strategy followed by some TV documentary narrators not to use certain conventional metaphors, such as SEA CRAB BEHAVIOUR IS ALGAE MOVEMENT, but instead present the viewer with documentary contents. By exclusively relying on the narrator's description of the behaviour as a swaying movement and its corresponding images in the visuals, the viewer is deliberately left alone to construct a metaphor out of the comparison crab-alga by him/herself. This ludic effect adds to the promotional appeal of the documentary and showcases the inferential power of visuals to produce metaphoric reasoning in the audience.

The next section elaborates on the incidence of multimodal metaphors in the popularisation of natural sciences. These metaphors do not exclusively arise from visual cuing, but from the conflation of at least two different modes of representation.

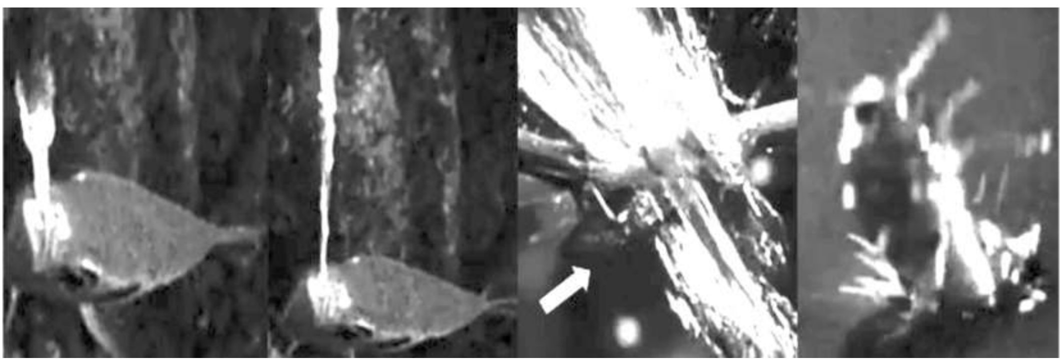
4. Multimodality

Forceville (2009, p. 24) writes that multimodal metaphors are metaphors whose target and source are each represented exclusively or predominantly in different modes. He also regards as multimodal those metaphors where the source is cued in two or more modes simultaneously. The biology examples discussed below fall into this second category. Accordingly, the target domains are conceptualised by different modes of the source domains. Among these modes are sound and music, which have only recently started to be explored (Forceville, 2009, p. 384).

4.1 The archerfish

Around three decades ago, the metaphorical basis of the archerfish (*Toxotes chatareus*) was verbally explained in a biology research article. Dill (1977, p. 169) found that "archerfish spit droplets of water at aerial insect prey, knocking them onto the water surface to be eaten […] the fish must deal with potentially severe refraction effects at the air-water interface". This finding had implications for ichthyology since it prompted biologists to make additional observations and refine their theories about the visual apparatus of some fish and how they find, capture, and eat their prey. In the verbal mode of expression of *archerfish*, the source and target are ARCHER and FISH, respectively. In addition, ARCHER is a WHOLE FOR THE PART metonymy, specifically ARCHER FOR ARCH, since it is the mechanism and shot of an archery bow that is compared to the spitting mechanism of a fish's mouth.

Popular science materials, especially documentaries, pick and choose diverse representation modes of metaphoric thought with a view to being as illustrative as possible and catching the viewer's eye. Accordingly, this subsection explores how the source domain of the metaphor *archerfish* is conceptualised, depending on whether it is cued by a verbal (speech) or non-verbal (sound effects) mode in a pedagogic setting. The focus of analysis is on the documentary video clip at http://www.youtube.com/watch?v=fhBZ40jIo4Q, which features the archerfish. Figures 12 to 15 are stills extracted from the video that sequence the predatory strategy of this fish.



Figures 12–15. Sequence of waterjet going out of the fish's mouth (11), cutting the air (12), and impacting on the insect (white arrow) (13), which falls down to the water (14)

The narrator's speech includes a number of words, such as *archerfish*, which is a technical term, and thus, a well-entrenched lexical item, and the expressions *expert in ballistics*, *weapon*, *water pistol* and *gun barrel*, which are novel sources that are recruited on-line to characterise *Toxotes chatareus*, the target, as a weapon user. This means that ARCHER, the original source coined by experts (see above), has been expanded to the broader domain WEAPON by the narrator for *promotional* (Nelkin, 1994) purposes. This expansion is also realised by the sound effect of a projectile cutting the air to characterise waterjets as arrows or bullets (see minutes 0: 12 and 0: 33, for instance) for the same purposes. Surprisingly, there is no visual realisation of the source domain – for example, the image of an arch(er) or a gun(ner) to be mapped onto the image of the fish, which is the target.

The promotional value of both the linguistic and auditory sources of the metaphor is evident, since they are intended to attract the audience. However, it is necessary to consider the question of what is pedagogically valuable about these novel sources as distinct from their entertainment or promotional value. Since the sound effect chosen is fairly generic, it may designate any type of arm and projectile. For this reason, this mode assists the terminological, and thus, conventional metaphor *archerfish* in describing the fish as an archer. This is a clear example of how a multimodal metaphor makes salient certain aspects of conceptual metaphors (in this case, the auditory facet of the source, which substantially enriches and supplements the whole weapon metaphor structure) that are inexpressible or backgrounded in its verbal or visual manifestation.

In contrast, the verbal items, such as *water pistol* and *gun barrel*, are at odds with the terminological metaphor, since they refer to *fire*arms. Broadening the source domain from BOW to WEAPON involves inaccurate mappings if the source domain *archer* is taken as a reference for the metaphor. For instance, *gun barrel* is mapped onto *the fish's mouth spitting water droplets*, which does not actually fit in with or does not make sense to the metaphorical term *archerfish*. Inaccurate mappings of this type are deliberately prompted by the narrator in order to enrich the whole metaphorical structure and make it more appealing to the audience; however, this strategy does not necessarily make the metaphor more instructive. In fact, it might be considered misleading. This case supports the claim that in the interest of public understanding, scientists and science educators should sometimes restrain promotional tendencies that lead to oversell (Nelkin, 1994, p. 30).

4.2 The velvet worm and the harvestman

This subsection describes auditory, visual, and linguistic metaphors included in the documentary video clip available at https://youtu.be/3DOvo2V8XIY?t=4m46s, which features two arthropods, the velvet worm (*Onychophora*) and the harvestman (*Opiliones*). Although these are metaphorical terms used by experts to refer to individuals of the Phylum *Onychophora* and the Order *Opiliones*, none of the documentary metaphors analysed here has anything to do with the metaphorical basis of such terms. The video contains both monomodal and multimodal metaphors.

One monomodal metaphor arises from auditory perception. From 4: 52 to 5: 03 in the video, a light and relatively high-pitched sound of violins can be heard as the images show the quick and dynamic marching pace of the velvet worm and harvestman along a tree branch. The choice of the high-pitched sound of violins is not random at all. In fact, this sound is the source of the metaphor, which maps onto the images of both animals making their way at a light pace, which is the target. This is a parallelism which the author of the documentary consciously establishes between light music and light pace, probably meant to be unconsciously interpreted as such by the viewer. This is a conventional strategy that is used in different settings, particularly in films as cinematic metaphors. What is novel with respect to the previous case studies is that both the source and target domains in this case, which belong to distinct modes of perception, are made explicit to work simultaneously. Thus, this is an example of *simultaneous cueing*, according to which, if two things are signalled in different modes, metaphorical identification is achieved by saliently representing target and source at the same time (Forceville, 2009, p. 31). In this case, simultaneous cueing adds liveliness and precision to the images, and is intended to help the viewer realise or be aware of the metaphor.

The light sound of violins – together with complementary sound effects, such as a sort of alarm (5: 05) and a brief clashing sound that is repeated at short time intervals, also helps to create an intriguing and disturbing environment, intended to draw the viewer's attention to a dangerous encounter between two animals. There are two factors that should be analysed here. The first factor is the high-pitched sound, which is embodied insofar as it keeps the viewer's expectancy up. This is a complex case of embodiment, which can be traced back as follows. First of all, the physical source domain UP is mapped onto the emotional state domain EXPECTANCY/INTRIGUE, since people tend to be on their feet at a moment of uncertainty (for example, in a forest, lost people vigilantly stand on their feet because they may be attacked by a beast).

The ensuing metaphor, INTRIGUE IS UP, is the opposite of RELAX IS DOWN. Subsequently, since a high-pitched sound causes emotional tension (e.g. the famous bath scene in Hitchcock's film *Pyscho*), a cross-domain mapping is established between the source domain HIGH PITCH and the target INTRIGUE, from which INTRIGUE IS HIGH PITCH arises. More specifically, we can speak of a co-occurrence (primary) metaphor since both elements (INTRIGUE and HIGH PITCH) co-occur in time. Accordingly, thanks to film watching experience, hearing a repeated high-pitched sound involves or anticipates an intriguing or dangerous scene. Being a primary metaphor, the distinction between INTRIGUE, the target, and HIGH PITCH, the source, is first and foremost their degree of subjectivity. INTRIGUE, a more subjective (hard to measure or quantify) concept, is understood in terms of HIGH PITCH, an objectively measurable unit. The production of feelings and emotions by sound/music is an effect that verbal metaphors cannot achieve so readily and effectively.

The second factor to be considered is the cadence of the violin sound, which follows a pattern of repetition at short intervals (a set of three-second long sequences starting at 4: 52 and ending at 5: 07). These quick sequences of repeated sound also contribute to creating a disturbing atmosphere. This effect has a physiological explanation: the more nervous we feel, the faster the rhythm of our heart beats. Accordingly, the QUICK MUSIC SEQUENCES are mapped onto the VIEWER'S HEART BEATS, which keep up with the rhythm of the music, thus producing a feeling of uneasiness in the viewer. If we link this mapping to INTRIGUE IS HIGH-PITCHED SOUND, the result is the compound/complex metaphor INTRIGUE IS REPEATED HIGH-PITCHED SOUND. As Grady (1997) claims, compound metaphors are constructed from the unification of primary metaphors, which are foundational.

The last metaphor emerging from sound also involves the mapping LIGHT SOUND – LIGHT PACE. Occurring almost at the end of the video at 7: 53, a short piano sequence of light notes can be heard as the velvet worm swiftly hides behind a rock. Each note on the piano seems to map onto each step that the worm takes to strengthen the sense of rapidness and lightness. This auditory device adds to the promotional, free-and-easy style of the documentary, which ultimately seeks to grab the viewer's attention.

The video includes verbal monomodal metaphors. The narrator uses lexical items such as *weapon, slime guns, razor sharp mouthparts, spiky armour,* and *chemical warfare* to list the number of defence and attack skills of the velvet worm and the harvestman. These expressions, which are not biology-specific terminological units, are closely linked to the vocabulary and the auditory strategy discussed in Subsection 4.1, including *archerfish*, *water pistol, gun barrel*, among other expressions, and the projectile sound effect. Far from being a coincidence, this convergence gives evidence that the biology discourse heavily relies on the WEAPON conceptual macro-metaphor to explain biological processes, especially in exegetical and educational contexts, where deliberate creative metaphors can be easily exploited. Based on all this evidence, we can be safe in suggesting that the entire video is built around the idea of a fight about to break out, where animal behaviour is compared to a battle (the Youtube clip title is even called *Monster Bug Wars*) or a boxing match (note the table typical for boxing that pops up at 5: 10 and compares the profiles and strengths of both contestants as if they were boxers). WAR/MATCH is thus the overarching metaphor theme – instantiated by visual, auditory and verbal cues – that substantiates and articulates the narrator's argumentation throughout the video clip.

It should be noted that the terminology of biology also draws on this conceptual metaphor in the form of terms such as *archerfish*, *sentinel organism*, and *evolutionary arms race* (cf. Ureña, 2011, where textual evidence is provided of the existence of the metaphor LIFE/SURVIVAL IS WAR). This means that sometimes the border between conventional metaphors and idiosyncratic ones is difficult to draw, particularly when conventional metaphors have idiosyncratic extensions (Forceville, 2009, p. 26). As Knudsen (2003) highlights, in addressing the general public, scientists use the 'closed' metaphors of expert discourse as 'open' metaphors in order to achieve their rhetorical goals.

Finally, the video contains a case of multimodal metaphor. In this metaphor, the target, the physical collision between the velvet worm and the harvestman, is cued by two sources belonging to different modes of representation. The first source is visually realised at 6: 01 and 6: 05 in the form of artificial flashes of light when both animals collide. Figure 16 and Figure 17 are stills extracted from the documentary film. Figure 16 illustrates the emergent flashes the instant at which the worm and the Opilion enter into frontal physical contact. For visual clarification, the worm's body as well as the harvestman's long legs are pointed by white arrows.

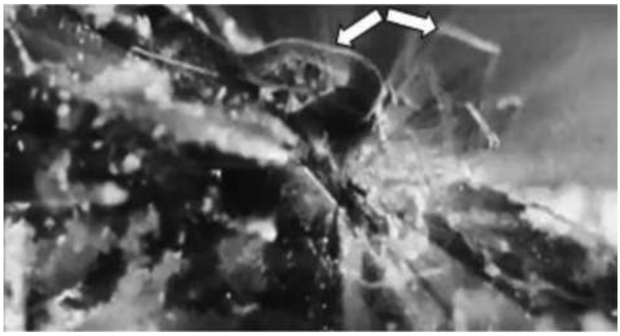


Figure 16. Emergent flashes of light at collision

Figure 17. Flashes during collision

These flashes are accompanied by brief percussion sounds, which are the second source of the metaphor, mapping onto the COLLISION target as well. Both auditory and visual effects are included by the author because of their spectacular nature, and thus, they have a promotional purpose.

4.3 Summary of contents

Based on authentic materials, the previous sections show how multimodal metaphors are used to popularise natural sciences among laypeople. Multimodal biology metaphors in documentaries normally include both auditory and visual artefacts, a combination that is intended to bring the appealing power of documentaries to full potential. Indeed, these metaphors are deliberately exploited by documentary narrators to draw audience attention. Particularly common in this type of pedagogical environment are resemblance metaphors, since comparison between concrete entities in shape, colour and/or behaviour are especially productive and easy to understand by nonprofessionals, and non-resemblance metaphors, which mostly involve acoustic effects.

The multimodal metaphors discussed above are good examples because they combine the verbal, auditory and visual modes. The verbal mode manifests as the terminological – and thus conventionalised – metaphors *archerfish*, *velvet worm* and *harvestman* and as nonconventional lexical metaphors, such as *water pistol*, *gun barrel* and *slime guns*. The narrators come up with the latter in a strategy where the conventional metaphor theme WAR/GAME is extended to associate a metaphorical term used by expert biologists with novel or idiosyncratic metaphorical expressions for explanatory purposes. This fact illustrates the great productivity of the WAR/GAME metaphor. It should be noted that this is a rare strategy to see in specialised biology research articles (see Ureña, 2016 for a detailed discussion of novel metaphors in scientific publications), but very frequent in popularising contexts. The metaphors *water pistol* and *gun barrel* are at odds with the terminological metaphor *archerfish*, since they refer to *fire*arms. Broadening the source domain from BOW to WEAPON involves inaccurate mappings if the source domain ARCHER is taken as a reference for the metaphor. Although clearly used for pedagogical reasons, *water pistol* and *gun barrel* do not convey meaning faithfully, and therefore, they might be misleading for the audience.

The auditory mode in the archerfish metaphor also involves expanding the WAR theme by relying on sound effects made by firearms, which is then equally appealing though potentially misleading to the viewer. Falling back on auditory metaphors to explain biological concepts and phenomena is also very rare in expert communication, but a common strategy in instructive and exegetical settings because they attract biology learners and laypeople and richly complement the visual and verbal metaphors. One metaphor in the acoustic mode in the velvet worm and harvestman documentary is LIGHT PACE IS LIGHT MUSIC, which may be unconsciously interpreted as such by the viewer. This interpretation is interesting in terms of the promotional value of the documentary because it draws on people's universal psychological responses to light and intriguing music and sounds. The level of entrenchment of this auditory metaphor in popularising videos of science is high, underlying a conventional type of music that is used not only in documentaries but also in films as a cinematic metaphor because of its great effectiveness.

The visuals that are metaphorically represented in the velvet worm and harvestman video clip are also intended to arouse interest in the non-expert audience. The intense flashes of light are artificially introduced in the video as a figurative manifestation of an unfriendly physical encounter or collision between two insects. Because of their unreal and sensational nature, these flashes achieve a degree of spectacularity, which assists the narrator in getting their message across to the viewer. Despite not being necessary to communicate scientific concepts, this multimodal device is extremely useful in pedagogical contexts because its spectacularity cannot be attained by the conventional verbal metaphors *velvet worm* and *harvestman* alone. For this reason, multimodality is highly instrumental to popularising scientific knowledge through metaphoric thinking.

An alternative metaphoric interpretation to LIFE/SURVIVAL IS WAR in the velvet worm- harvestman video clip is LIFE/SURVIVAL IS DRAMATURGY. In fact, most viewers/students of this type of biology documentaries are accustomed to seeing video dramas that include various sensorily-stimulating audio/visual devices that naturally map onto the observed features of the target LIFE/SURVIVAL. This high level of familiarity buttresses the pedagogical and promotional value of the SURVIVAL IS DRAMATURGY metaphor. The video clip includes staged interactions of actors with roles played out in scripted fashion (the AGGRESSOR is mapped onto the VELVET WORM, whereas the VICTIM is mapped onto the HARVESTMAN). Within this framework, there is also a hierarchy of status (DOMINANT-VELVET WORM and SUBMISSIVE-HARVESTMAN). The staged interactions of actors are featured by means of alternating sequences of the animals' SLOW AND RAPID MOVEMENTS and COLLISIONS, which are metaphorically interpreted in terms of SOFTER AND HIGH-PITCHED MUSIC and FLASHES OF LIGHT. The music, sounds, and light flashes map onto the rise and fall of the viewers' emotions, which are typically stirred while watching drama performances. Importantly, there is a narrative underlying all of these metaphorical mappings and comparisons, that is, survival of the fittest.

These visual, auditory and multimodal metaphors crucially reinforce and contribute to the dominant metaphor SURVIVAL IS DRAMATURGY, providing the narration and the story behind it with thematic cohesion and structure. Being sensational and attention-grabbing, these metaphors are also key to promoting the documentary.

5. Conclusions

This paper provides textual, visual and auditory evidence that nonverbal and multimodal metaphors are well integrated into the construction and teaching of biology sciences. It shows how different semiotic modes, including static and dynamic (body language) images as well as sound/music, work separately or together to construct figurative meaning. The resulting metaphors reveal aspects of biological patterns that cannot be readily accessed through terminological metaphor. Some of these metaphors – mostly visual in nature – are theory-constitutive, which means that they are conventionalised metaphors that help (re)structure and classify scientific findings, enhance theories, and eventually, further science. The tree metaphor is a good example since it permits scientists to organise knowledge and biological elements in a structure, where scientific disciplines are hierarchically arranged as roots, related to each other in terms of relevance and degree of connection to a main discipline. For this reason, tree metaphors can be said to have a particularly rich and productive structure, which fosters interconnections between specialised concepts, and have inference structure.

Some tree metaphors, such as EUGENICS IS A TREE and DISCIPLINES ARE TREE ROOTS, are readily identifiable because the source domain is visually portrayed. Non-resemblance metaphors are also common, and can be easily distinguished from resemblance ones. This is the case for the non-resemblance metaphor IMPORTANT IS SUPERFICIAL AND PROXIMAL, which subserves the tree metaphors EUGENICS IS A TREE and DISCIPLINES ARE TREE ROOTS.

Inference structure is particularly useful because it stimulates further observation of natural entities and processes. For example, by setting the metaphor SEA CRAB BEHAVIOUR IS ALGAE MOVEMENT, biologists can search for animal behavioural patterns similar to the specific behaviour of the crab species *Pisa armata* (e.g. some fish imitate loose leaves that drift side to side in the tide), and then make comparisons and associations, and establish contrasts. These metaphoric comparisons feed imagery and boost imagination, which assists scientists in inferring or hypothesising why and how this biological/ecological paradigm occurs across animal types, extending or restricting the paradigm.

From a pedagogical point of view, metaphors such as the one mentioned above make explanations of animal behaviour and cognition more appealing to the laypeople since principles of cognitive psychology are normally difficult to understand by a non-specialist audience. Biology teachers and scholars using metaphors of this kind incite learners to value the wide scope, applicability and great popularising potential of metaphors. For example, the metaphor DOMINANCE IS UP, attributed to the Brazilian wandering spider, is meant to encourage students to somehow identify animal species with humans, which attracts their attention and makes learning specialised concepts and phenomena (in this case, the way some species behave and interact with antagonists for survival and predatory purposes) more amusing.

Moreover, sophisticated animal behaviour also raises questions about the actual complexity level of animal cognition. An insight into the bodily postures and responses of certain animals to predators from a metaphor-based perspective should encourage biology scholars to open up new lines of investigation towards finding evidence of reflective, and perhaps, metaphoric reasoning in non-human species. There is evidence of the activation of specific brain structures during metaphoric processing in humans (Rapp, Leube, Erb, Grodd & Kircher, 2004). This type of reasoning could be put to the test in experimental neurobiological studies of non-human animals, especially because the scientific community continues to be in need of psycho-cognitive experimentation that painstakingly looks into the ecological and cognitive-semiotic grounding of imitation patterns in animals. Findings in this direction would crucially contribute to construct path-breaking theory in the burgeoning field of comparative anthropological zoosemiotics, which makes comparisons between human and non-human semiosis with a view to establishing potential connections between the two codes (Maran et al., 2011, p. 9).

Other metaphors are deliberately used by educators to explain biological phenomena to laypeople incorporating auditory devices for clearly promotional purposes. Specifically, the effective and sensational effects of visual and acoustic resources cannot be produced by terminological metaphors alone, hence the significance of multimodality in pedagogical contexts. Metaphors of both types can emerge from resemblance and non-resemblance patterns. Non-resemblance metaphors are mostly primary metaphors or are based on them. Visual resemblance metaphors are mostly unconventional/idiosyncratic as well as highly imagistic. Because of their creative nature, the use of metaphors that do not map accurately is not uncommon in these communicative situations. For example, the verbal metaphor *gun barrel*, used by a documentary narrator to support the visual representation of the metaphor *archerfish*, does not actually fit in with the latter (GUN IS A FIRE WEAPON). Even though it may be misleading, using *gun barrel* to explain and describe the behaviour of a fish species may nevertheless be beneficial overall, because it enriches the whole metaphorical structure and makes it more appealing to the viewer.

The evidence provided in this paper is a contribution to the study of facets and types of metaphor that are all around us, but which have been rarely addressed in research. As has been shown, nonverbal and multimodal metaphors play a major role in helping biology experts pursue their science more effectively and in attracting natural sciences learners and nonprofessionals by explaining abstract and complex concepts in an amusing and striking manner.

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PART III

Metaphors in specific fields of social sciences and the humanities

CHAPTER 7

Three metaphors in social science

Use patterns and usefulness, separately and together

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Independent

Metaphors appear in scientific theories, guide scientists, teach students and fascinate the public. This chapter sketches a kind of vocation or métier for scientific metaphors in physics and then applies the same outline to three influential conceptual metaphors in social science – DATASET, SOCIAL FIELD, and DYNAMICAL SYSTEM, along with their respective sub-mappings. All three are in continuous use and often reliant on each other. Using corpora derived from recent social science literature I show how metaphors stimulate hypotheses, then are extended to account for results in successive rounds of observation and theory development, tracing the degree to which each metaphor is useful and retained over the years. Of special interest are supplementary metaphors introduced deliberately to summarize complex source domains.

Keywords: science metaphors, social science, field theory, datasets, dynamical systems

Introduction

With so much commentary on metaphor as used in the experimental "hard" sciences, it is opportune to provide some balance by expanding into the "softer" social sciences – long believed to be less rigorous, with loosely defined methods and highly speculative theories. To the degree that these beliefs are true, this reflects how social science is still at the stage where general principles are being sought and scientists are learning how better to investigate realistic social interaction.

Social science theories are many and varied and metaphors play a large role in their development and application. A metaphor influences how scientists think about their subject matter, how they frame it, the inferences they make and the substantive questions they ask. Once established, metaphors are used in pedagogy and popularization. Metaphors draw attention to some features while

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masking others, even introducing specialized terminology. They are likely to be key in judging whether the scientific answers and communications to the public are valid. Noting how some have a long career in science, are changed, perhaps abandoned, then re-applied, no metaphor can be assumed to remain static. Using current understandings of conceptual metaphor and corpus-based methodology this chapter attempts to add to our understanding of how scientific metaphors come into use and evolve.

Objectives of this chapter

Examining metaphors in social science offers opportunity to learn more about metaphor broadly, because theoretical understanding in social science is more tentative, more reliant on, and illustrative of, the generative and creative powers of metaphor. So in this chapter, as the social science theories are described and reviewed, I attempt to track several things:

First, the description of the various theoretical approaches should make clear that they are by no means entirely, or even mostly, metaphorical, but combine literal and figurative notions into a stew of reasoned argument, analogical comparisons, and unconscious (often metaphoric) assumptions. I focus on the metaphoric aspects, attempting to identify key or central metaphors, but making no claim to finding all.

Second, I propose a kind of framework for how metaphors in science first appear, guide the science, are modified based on observations, and might be retained and combined. This is the métier or vocation of scientific metaphor that appears below.

Third, and closely related to the second, is the goal of showing how scientific metaphors fulfill the tripartite functions of communication, cognition or reasoning, and the deployment of textual or language elements.

Finally, I try to show the general usefulness of the metaphors discussed, not only to scientists and specialists, but also to non-specialists.

1. Metaphor vocation or métier, and study method and organization

The following subsection outlines what I am calling the scientific metaphor métier or vocation (cf. Bowdle & Gentner 2005; Knudsen 2003, 2005). It uses an example from atomic physics that deals with "hard" science that may be easier to follow at this point. Many find the social sciences vague and confusing. For this reason, I apply the métier outline first to something more familiar so as to provide a template that I can then apply to social science.

1.1 Vocation or métier of scientific metaphor: Atomic physics example

Metaphors used in scientific discourse are seen here to have a career path which, in recognizing their importance in the conduct of science, I refer to as a vocation or métier. This shows how metaphors function differently to structure thinking at various points in their history, their usefulness to scientists and laypeople, or as tools of one theoretical school or another. A given metaphor is far from being simply present or absent in a discourse. It not only influences science, but also is influenced by science. So, as it is used, its functions or the roles it plays can change. These changes affect a metaphor's flexibility as a resource to manage emergent meaning, and a goal of this chapter is to give examples and begin to catalog not so much the specific source domains, but how they are used.

The description of such a vocation or métier is divided into three broad stages: the early application of a metaphor, its modification, and its continued use. Even metaphors that are used over a period of years may not pass through all these stages, sometimes they pass through the same stages repetitively, nor will they necessarily follow the order given. This exposition and the examples studied here are intended to offer a framework to better understand the diverse ways metaphors evolve and coexist, particularly in highly complex scientific fields.

Early application of a metaphor

A metaphor may frame discussion and suggest how things work, offering a way to think about the scientific topic in question.[1] A metaphor draws attention to important points, sometimes offering terminology for things or events that are observed but have no name. Look for scientific metaphors derived from culturally entrenched ideas (Kövecses, 2010), recent science or technological advances in other fields (Giles, 2008). Such a metaphor depicts a more complete, often idealized, macroscopic event than may have been scientifically observed (Brown, 2003). Using a metaphor, especially an entrenched and vivid one, may seem to offer literal knowledge (Wolff & Gentner, 2011).

For example, when electrons were observed to be in motion, the atom was metaphorically portrayed in terms of the long-accepted Copernican model of the solar system: Electrons were metaphorically understood to be very small objects (particles) moving around a larger nucleus (Lerner, 2016).

1. Metaphor functions are identified in the introduction to this volume and by several authors, including Low (1988), Gibbs (1994), Goatly (1997); condensed to three functions by Steen (2008, addressed later); summed up by Denroche (2015).

Mapping to observations

Having been tentatively introduced as a macroscopic framework, scientists may take advantage of conceptual and inferential structure and attempt to map the metaphor's features to what might be observed at a more detailed or microscopic level (cf. Justi & Gilbert, 2002). Taking this step means the metaphor is being used for more than a general frame or vague perspective. For the moment, at least, it is theory constitutive, provides "epistemic access" (Boyd, 1993, p. 485; see also Hallyn, 2000; Steinhart, 2001), and its structure will be put to work inferring details and proposing hypotheses. For scientists this ideational work guides subsequent scientific observation; for teachers and students these mappings can be pedagogically valuable (see Aubusson, Harrison, & Ritchie, 2006; Harrison & Treagust, 2006).

In the example, counter-balanced, less massive planets in orderly orbits are metaphorically mapped to moving, negatively charged electrons; the much heavier, stationary sun is mapped to the positively charged atomic core or nucleus; the counter-balance of gravitational and centrifugal forces is mapped to the balance of positive and negative electrical charges; and the whole metaphoric system seems to operate according to Newtonian principles – an appealing formulation based strongly on our common experience of bodily movement. Investigators are thus primed as to what to look for next – electrons traveling in identifiable orbits around the nucleus.

Subsequent observations test metaphoric mappings

Although distinct orbits were not found – that is, planetary movement did not map well to electron movement and Newtonian mechanics failed – the solar system metaphor had been fully effective in prompting useful questions. Atomic particles turned out not to show characteristics of the tiny, revolving billiard balls expected; their motion was not reducible to a clear statement of position and momentum over time: the ontology of Newtonian movement in Euclidean space no longer would seem to apply.

Metaphor modification, changing the metaphor

To account for what is actually observed, to continue to be useful, a metaphor may be clarified, modified, or replaced. As scientists learn more detail about the target (Semino, 2008), the metaphor might be extended or elaborated (Lakoff & Turner, 1989), "helped" (see below), blended with other metaphors, (Fauconnier & Turner, 2002), closed (Knudsen, 2003), or replaced entirely. Change in metaphor can lead to change in language that may be more or less effective in generating hypotheses and communicating scientific insights (see, for example, Heywood & Parker, 2010).

In the example, a kind of metaphor replacement occurred. Characteristics of waves were detected – waves as had already been analyzed in the study of sound, fluids, and light, and for which mathematical formulations and computational tools existed. Building on conceptions well-established in these other fields, Schrödinger's wave equation took the place of the metaphor of orbital paths for each electron, and from this formula the relative probability of electron location is computed (Higbie, 2013; Freiberger, 2013). At this point the solar system metaphor lost most of its theory constitutive status, replaced by the wave equation.

Loss of simplicity

As scientists dig deeper, trying to comprehend new and diverse observations, they may put aside the initial metaphor, which might have been very simple and idealized, dependent on embodied or primary metaphors (Grady, 1997), to picture how things work. If the coherence of the idealized model or schema is disturbed and new – perhaps mathematical – terminology applied, this may be comprehended easily enough by specialists, but not necessarily by others (as exemplified by Halim, et al., 2013).

The detection of waves introduced aspects of quantum mechanics. Quantum mechanics was widely used by specialists but, unlike Newton's laws, was not something easily grasped through an embodied source domain. Potentially confusing, even disturbing, to scientists and students alike, quantum mechanics did not promise a clear picture of an electron's velocity and position as the framework of Newtonian mechanics leads one to expect. There was no longer a step-by-step physical account of particle motion, but instead an abstract and non-embodied conception of wave motion that conformed to a second-order differential equation.

Metaphor closing

As more micro-level detail is learned about a topic, the true, metaphoric qualities of a theory constitutive source domain fade because they no longer seem needed. Some or all mappings to the target have been replaced by literal knowledge (Semino, 2008); the familiar and favored metaphor "closes", is no longer generating ideas (Knudsen, 2003), even while its lexical representations might still be retained as literal descriptions (even dictionary definitions); it seems to have lost its metaphoricity (no longer mapped to the metaphor source domain) and "died", perhaps becoming a "law" or formula. If the structure of the metaphor is implied and continues to convey ideas fundamental to a scientific topic it may be called a "background metaphor" (Blumenberg & Savage, 2010).

In specialist literature "orbit" became technically defined in terms of discrete energy levels. In losing its solar system metaphoricity, the solar system metaphor closed, becoming a background metaphor. It was still depended upon to characterize electron motion, such as their going around the nucleus, even as the wave metaphor and Schrödinger's wave equation was employed, as described further below.

'Helper' metaphors
After a simple, idealized metaphor has been superseded, scientists and science writers whose audience is learners or lay people, often borrow or invent what I choose to call "helper" metaphors. These are direct, intentionally-used metaphors, often novel forms of conventional ones, that offer a different point of view of the topic under discussion, providing "scaffolding" (per Vygotsky: Verenikina, 2008, p. 1; also see Denroche, 2015; Talmy, 1988) or "stepping-stones" (Steinhart, 2001, p. 7) in communicating a perspective that non-specialists can grasp.

In the example, the idea of orbits was sidestepped and an "electron fog" was introduced. Electron location and velocity metaphorically understood as 'fog' changes a learner's perspective, perhaps by invoking the difficulty of locating objects through a foggy atmosphere. In fact, the fog metaphorically represents a probability distribution of possible momentary electron locations, so the "fog" has no substance. In this way a learner is "helped" to transition from a Newtonian to a quantum mechanics perspective. Similarly the idea of electrons randomly "jumping" between energy levels "helps" a learner begin to understand how the abstraction "principal quantum numbers" is used to describe an electron's state. Helper metaphors, however, ought to be seen as expedients, because one or more key mappings is erroneous or misleading. You would be entirely misguided if you tried to observe the density of the fog or the force and direction of the jumping.

Reiteration of process
Putting aside any such erroneous mappings, if the changed metaphor hasn't entirely closed, it suggests what to look for in forthcoming observations. As before, hypotheses are formed and the process reiterated. This example illustrates what can emerge from the back and forth interplay, often involving years of questioning, metaphor-influenced conceptualizing and testing through experimentation. More metaphor elaborations and extensions may be introduced to address unanswered questions, explain new observations, and new "helper" metaphors devised for learners.

Continued use of a metaphor
A scientific metaphor would be retained in use over years and decades if it is effective in one or more functions attributed to metaphor: communications, conceptualization, and lexicalization (Steen, 2008). More specifically, here are reasons we could expect a scientific metaphor to continue in use:

- It explains at least some scientific observations, such as results of some experiments.
- And does so in alignment with, or appropriately alters, the viewpoint of some constituency, including scientists, students, science writers, journalists, or the lay public.
- Or it has introduced language or terms that become entrenched and continue to be used.

In the example, some mappings of electrons as orbiting particles were retained to explain certain findings, even as the metaphor of electrons as waves gained ascendance; this will be taken up below.

The afterlife of metaphors

Changing or superseding an earlier metaphor does not necessarily mean that the simpler initial metaphor goes away. A metaphor may have appeal beyond its correspondence with the latest research and may be more easily believed than is the data. Scientists, scholars, as well as learners become dependent on it to summarize a topic or to make things memorable to students. Sometimes a metaphor once used by scientists to explain a particular subject, but later discarded, re-emerges as the best fit to certain observations (Knudsen, 2003).

Two or more distinctly different (sometimes incommensurate) metaphors may be in use simultaneously with regard to aspects of the same phenomenon. They coexist, and which metaphor is used depends on what in particular is being studied and for whom results are intended. A previously closed metaphor can be resuscitated or "re-opened" in non-specialist exposition or when applied to a different but seemingly related topic; that is, its metaphoricity is recovered and understood by some audiences (cf, Giles, 2008; Knudsen, 2003).

In the example, the introduction of the wave metaphor lead to better understanding of electron movement, but did not explain all observations that atomic physicists made. Diffraction experiments and photoelectric effects were better explicated by continuing to regard electrons metaphorically as objects or particles. Because no single metaphoric model would explain all observed aspects of subatomic behavior, both the particle and the wave metaphors are retained and used, depending on the focus of research. An electron, conceived as a particle, was nevertheless found to have wave-like properties; subsequently it was established that anything conceived as a wave also had some particle-like properties. This became known as the wave/particle duality (Nemitz, 2000).

Furthermore, both of these metaphors found roles in pedagogy – with the solar system metaphor (electron understood as object or particle in orbit) continuing to be used in physics texts as an introduction to subatomic motion, and the wave idea (electrons understood as a billowing wave of energy with no mass) is also introduced to learners (Taber, 2013). Their simplicity as introductory stepping-stones gives them additional reason to live on.

1.2 Organization of the study in Sections 2, 3 and 4

The previous subsection gives the general outline of what I am calling the scientific metaphor métier or vocation. I chose the atomic physics example above because it is familiar to many and based largely on well-established science. The next three sections offer a more extended account, applying the métier outline to three distinct metaphors, all mapping to the same social science topic or target domain. The topic – social conflict, particularly fraught or volatile social conflict – is challenging to study and anything but settled.

Sections 2, 3, and 4, below, present successively the three contemporary social science approaches or theories as applied to this topic. In general these theories or approaches are described by their adherents in conventional terms – probably intended to be mostly literal, and documents containing these descriptions form the corpora for each section. But within them the metaphor scholar may identify important conceptual metaphors. I attempt to elucidate these metaphors with their sub-mappings, show how they map to known features of the theories, and identify hidden construals where I detect them. As the above discussion of the vocation or métier illustrates, it becomes possible to see how the metaphors enable scientific understanding, help generate hypotheses, guide ongoing scientific observations, interpret results, frame and explain all of this to non-specialists.

1.3 Method

The methodology used here is based on conceptual metaphor theory (Lakoff, 1993), and related work (Cameron, 2003; Charteris-Black, 2004; Eubanks, 2000; Fernandez-Duque & Johnson, 1999; Semino, 2008). Metaphor identification is based on procedures used effectively by others and consisted of manually identifying figuratively used words or groups of words, the strictly literal meaning of which is incongruous or outside the given context of the target; such figurative words are usually less vague, less abstract, more concrete or physical.

Adhering to the corpus approach to metaphor investigation which is, in general, the method used here, the intent is to find metaphors as they are actually used in the scientific discourse of interest. This manner of investigation does not survey all metaphors used in the discourse. The goal is to select those that appear to be truly exemplary in exploring, elucidating, investigating social processes.

To focus the study I first identified a social science topic of contemporary interest, as mentioned above: fraught or volatile social conflict, and I make use of the example of encounters between police and alleged crime suspects. Then I looked at three different theoretical approaches used in the scientific study of this topic; these can be identified as the database or dataset approach, the social field theory approach, and the application of dynamical systems theory.

For these three social science approaches or theories I selected scientific publications that generally described each, particularly as related to such conflictual encounters. These texts form three corpora, one for each approach or theory. Entire texts are used, omitting endnotes, appendices, and reference sections (see Appendix 1 for relevant details such as citations and text lengths).

I then identified the parts in each corpus describing relevant theory, and closely read those parts, looking for both conventional and novel metaphoric language. The central metaphor or metaphors for each corpus were sought, where the target domain remains essentially the same across the three corpora. This is not a word-by-word analysis, but requires comprehension of authors' theoretical arguments in their entirety or by major section. As detailed in Sections 2, 3, and 4, below, where there are numerous text examples for inspection, three central conceptual metaphors emerged – one in each approach or theory. Labeled per their source domains they are DATASET, SOCIAL FIELD, and DYNAMICAL SYSTEM. Once major metaphors were identified, key sub-mappings were then identified.

Of course, issues may arise regarding such an identification procedure, and whether the metaphors named are actually conceptual in nature – indicative of how the social scientists actually think – not mere lexical configurations illustrating how they use words. Such issues will not be resolved here by focusing on the precision of the methodology. My description of the vocation or métier of scientific metaphor, above, outlines ways that metaphor is useful in science, including how a metaphor communicates, adds to the language, and guides thinking; so the metaphors identified can be judged accordingly. Furthermore, the results given in Sections 2, 3, and 4 constitute additional criteria, when viewing the text extracts in particular, to judge whether the metaphors identified make sense in the context of related theoretical presentations.

2. The dataset metaphor in the study of social conflict in police-suspect encounters

For those who read the social science literature, a social scientist's comment to a reporter about his work on this rather troubled and contentious subject is not surprising: "You know, protesting is not my thing," he said. "But data is my thing.

So I decided that I was going to collect a bunch of data and try to understand what really is going on when it comes to racial differences in police use of force" (Bui & Cox, 2016).

Social science has been dominated by the use of tabulated data collected after the underlying social processes are completed. The form of datasets and how they are put together have their own logic, regardless of what the data supposedly represent, and so can influence how scientists think about their subject matter and the inferences they make. I argue in this section that the dataset, when heavily depended upon, is a metaphor for the actual social encounters or processes that are the subject matter of social science. The conceptual metaphor I propose at this point is stated as SOCIAL PROCESS IS DATASET. While any field of science could be said to be metaphorically understood as the methodology used in its research, this might be seen as a central mapping (Kövecses, 2002) and have special implications for social science.

Such methodological metaphors are consequential. As with all metaphors, they frame discussion and suggest how things work, encouraging both scientists and lay people to think accordingly about a scientific topic in question. This happens through the generation of indirect comparisons between metaphor source and target domains where valid inferences in the source are projected onto the target (Schön & Rein, 1994). Although no experienced social scientist will necessarily take such a metaphor literally, these ideas frame the discussion, and are given greater salience. I argue here that the metaphorical representation of social interaction as data or dataset projects a system of categorized discrete attributes, metaphorically understood as physical objects, among which are orderly, arithmetic, readily-computed relationships that are precise, clear, stable, and reliable, onto the target domain of human social interaction.

The dataset metaphor licenses inferences about the actual encounters that, because the scientists have little or no direct experience with them, are influenced not only by what the data supposedly represent but also by the properties of datasets – the methods of forming and manipulating them and their distinctive structure.[2]

In this section I identify the target domain of police-suspect interactions noting that they contain important features of conflict in social processes. These interactions involve conformity and compliance. A special case from the field of

2. It would not be entirely whimsical to simplify this to REALITY IS STATISTICS. "When scientists accepted the implications of the Uncertainty Principal and began describing reality in terms of statistics, the lay public got the idea that reality was actually like that" (Debate #17142, 2011). If respected scientists are perceived to believe certain metaphors are literally true, lay people may adopt such beliefs uncritically.

crime and law enforcement, of particular current interest in the United States, is when the police encounter people suspected of dangerous criminal acts and compliance can legitimately be coerced. Vested authority is expected to make reasonable, rational decisions about the use of brute force to get citizens suspected of wrongdoing to comply.

This is the example I will use to explicate the dataset metaphor. To focus the discussion further, I pose specific questions: Are the police more violent in dealing with racial minorities than with the majority white population? Is the level of violence rational in light of circumstances?

2.1 Looking for answers in official records: Early application of the dataset metaphor

Before getting more deeply into the scientific study of these questions, what do the "official" records say? Official records tend to be simple counts of events with minimal cross-tabulation of their characteristics. These resemble bookkeeping ledgers where essential accounting data is recorded, in this case the data is from police and court records about police and alleged criminal behavior. Journalists and many lay people look to such official data for answers and give them quasi-scientific status. Such records are organized as a very simple dataset, so the dataset metaphor (perhaps unconsciously) is operating when the numbers are seen, supporting the belief that they tell what we need to know about actual events. This promotes and helps conventionalize the SOCIAL PROCESS IS DATASET conceptual metaphor.

The official records say that, currently in the entire United States, there are approximately 1,000 deaths of citizens in encounters with police per year. Roughly 50% are black (for the nation as a whole, black people make up approximately 12% of the population and their rates of arrest and of incarceration are likewise disproportionately high). Together with examples of gruesome cases described in the media where black citizens were shot by police, it is not surprising that so many people embrace the official numbers and are convinced that violent acts committed by police towards blacks greatly exceed those towards other groups.

2.2 The dataset as tool of social science: The dataset metaphor and its sub-mappings

How datasets are formed

Social scientists, like the one quoted at the start of this section, undertake to collect more detailed empirical data and fully understand what it says before giving their conclusions. What do we need to know about datasets to understand what form the DATASET metaphor takes?

Police behavior when apprehending suspects is a real-life social phenomenon that might be studied holistically as a naturally occurring event. But this would require trained observers on hand to collect data where and when these encounters happen to take place. Also, being observational in nature, not experimental, there is no random assignment to control groups and key variables cannot be isolated. Consequently, the study of such encounters takes a form quite typical in social science. It is done in terms of static, surface data gleaned after-the-fact from official records already available or readily collected, and then numerically coded.

The data are organized into an array where, for example, the columns contain a number or code for each data item (or variable) in one encounter or case, and each row corresponds to all such data for an individual case. The arithmetic summaries of the dataset, taken over all individuals together, produce descriptive statistics (such as means, variances, frequency distributions, and correlation coefficients).

One or more of the data items represent the outcome of concern – here, police violence directed towards suspects. Social scientists want to figure out what has happened in the social situation and what might cause each outcome. Typically they manipulate these datasets, following accepted computational procedures, trying to predict outcomes (dependent variables) from data on predefined background and situational factors (independent variables). I am arguing that the dataset conceptual metaphor frames the thinking, and guides the research of these social scientists; this is most evident when the operations of three principal submappings are considered.

Data are collections of objects

In a very basic way, the dataset itself is a metaphor: SOCIAL PROCESS IS COLLECTION, MANIPULATION AND INSPECTION OF OBJECTS. The variables are collections of objects (things, entities or events that can be thought of as objects) taken from records and numerically coded. Numbers so organized, and numeracy in general, can be considered metaphorical. Lakoff and Nuñez (2000) and Guhe, Smaill, & Pease (2009) have shown that addition, subtraction, multiplication, and division, and the objects on which these arithmetic operations are based, are conceptual metaphors. They argue that a person's bodily experience of interacting with real, physical objects shows that they can be grouped and manipulated, such as by adding them to or removing them from groups and by combining groups. The regularities experienced in doing this form metaphorically the concepts and operations of arithmetic. Patterns among variables, including calculations of statistical parameters (mean, variance, etc.), are discerned in the aggregated data and used to answer social science questions of the sort posed in the example here.

This method of study fits well with what has been called "substance-ontology" (Seibt, 2008), a set of presuppositions that underpin so much scientific thinking, namely, that discreet, bounded, concrete things, pieces, objects and substances are primary. Furthermore, these objects or substances exist on at least two levels, hierarchically organized – the micro level of individual cases with concrete attributes, and the macro level where all cases are aggregated and generalizations made; in this conception the macro level is reducible to, and fully explained by, the micro level (Christen & Franklin, 2002).

Quantification is paramount in science
And a metaphoric mapping promotes this: PRECISION/ACCURACY IS ASSIGNING NUMBERS TO OBJECTS AND MANIPULATING THE NUMBERS. The objects are numeric quantities and codes, as just described above. Their numeric definitions are clearly communicated and engender certainty that they are real, concrete and enduring like substances, quantified and recorded, so the data is understood as empirical "fact." All interpretations thereafter are framed as fact. In this way observations not only achieve mathematical precision, but the dataset also exists in its own right so it easily becomes an object of study. This is the more salient because social scientists and the public rarely experience directly, or observe others experiencing, the domain of phenomena being studied, although they may have heard anecdotal accounts or seen videos. Nor is there any real or imagined physical model of the social encounters analogous to physicists' solar system model of atomic structure. Instead social scientists rely on the domain of coded data, of which their training and research experience has given them extensive, first-hand, grounded experience. The dataset is a proxy for, not at all the same as, the real events, but it provides mental access (Kövecses, 2006) to what happened in police-suspect encounters.

Although a proxy, the various elements of the dataset, numeric quantities and codes, correspond to a restricted subset of elements in the actual police-suspect encounters. In this sense there is a mapping between these two domains (Coulson & Oakley, 2003) where the dataset is an attenuated, concrete representation of a large and complex set of real-life events. The language of datasets – variables, averages, correlations – predominates over psychosocial terminology, as illustrated by textual extracts, below. This further argues that the specific organization of the dataset and its typical manipulations structure how results are communicated and understood; they influence the cognitive inference process and the formation of substantive questions.

Causation is central to scientific inquiry and is metaphorically understood
CHANGE IS ONE ENTITY PUSHING ANOTHER SO AS TO MOVE IT. Causation is classically seen as one thing touching, pushing or banging into another (Lakoff & Johnson, 1999; Martin, 2003).[3]

Statistical relations among the variables are examined in an attempt to interpret cause and effect. If the outcome variable (police violence) and some other variables (e.g. race of suspect) co-vary, by both occurring in one case, and both not in another, and this pattern generally holds over large numbers of cases, causality is readily inferred. With the data collection and tabulation process as the source domain, movement (change) in variable A accompanied by corresponding movement in variable B is understood as A causing B. By examining the results of such tabulations the scientists answer questions such as, was coercion used with suspects of one race more than another, or did the aggressiveness of suspects influence coercion?

As Lakoff & Johnson (1999) point out, causality is metaphorically understood as an entity applying force to move another entity, producing change in the latter. Deprived of more direct apprehension, recasting such entities as variables in a dataset, one may subconsciously depend upon the mental image of physical force, as in classical mechanics, originating in one variable, impelling the co-variable into a certain state.[4]

To summarize, substance-ontology, classical notions of causation that it facilitates, together with the quantification and potentially precise evaluations possible, form practical tools for scientific exploration. The three sub-mappings just considered (1. SOCIAL PROCESS IS COLLECTION AND MANIPULATION OF OBJECTS, 2. PRECISION/ACCURACY IS ASSIGNING NUMBERS TO OBJECTS AND MANIPULATING THE NUMBERS, and 3. CHANGE IS ONE ENTITY PUSHING ANOTHER SO AS TO MOVE IT) express what is meant by SOCIAL PROCESS IS DATASET. These notions guide empirical observations and their interpretations.

2.3 Mapping to observations: How the individual case is understood from aggregations

So far we have seen that when social science is treated as calculation, one can easily be persuaded that the specific case derives from the general case, that future

3. The source domain of MOTION is based on the image schema structure source-path-goal and possibly direction (Radden, 1996).

4. To an unknown degree the dataset metaphor could inherit the logical structure (Feyaerts, 2003) of the causation as mechanical force metaphor; then the dataset metaphor licenses inferences such as movement (change) in variable A causes corresponding movement in variable B.

outcomes are summary calculations on past data, or aggregation of the entire dataset. This happens even though social scientists may be generally aware of the "ecological fallacy" (the fallacy of drawing conclusions about an individual case based on group averages; see Protnova, Dubnov, & Barchana, 2007, for general review). Such framing does not tell a true story, but it is communicated easily, seems to offer precise and scientific understanding, and so this rendition easily becomes conventional.

Add to this the exemplary nature of group statistics; they can be understood as prototypical, and the consequence is that actual, individual encounters or cases are easily inferred as conforming to the prototype. For example, use of force in an encounter is understood as percent of a given group who have experienced it in the past; part of the cause of violence is inferred to be variables coded for race and codes for the suspect's reaction to the encounter. When this is done, averages are construed as (mapped to) the typical outcome for individuals of a certain racial group, and percentages construed as probabilities that lethal or non-lethal violence will occur.

Corpus examples of scientific language talk about individual cases in terms of aggregated data. So we have, for example, the likelihood that the police will shoot a black man in a particular encounter interpreted as equal to the percent of black men in the entire dataset having been shot by police; the variance construed as the uncertainty of such an outcome. A table of descriptive statistics for all subgroups of encounters stands for the entire state of affairs regarding police-suspect encounters. Language in excerpts below may seem to be describing actual encounters, but are in fact referring to tabulation of data codes, only abstractly connected to behaviors that unfold in particular situations. Metaphoric mappings are reinforced even where the scientist interprets cautiously.

(1) …as the <u>intensity of force increases</u> …the <u>probability</u> that any civilian is subjected to such treatment is small, but the <u>racial difference</u> remains surprisingly <u>constant</u>

(2) …it's not obvious how to <u>aggregate</u> non-compliance into a monotonic index … A simple <u>aggregation</u> of the number of non-compliant activities is likely misleading.

(3) …blacks and Hispanics are <u>more than fifty percent more likely</u> to experience some form of force in interactions with police.

(4) …to explore whether racial differences in the <u>frequency</u> of officer-involved shootings are <u>due to</u> police malfeasance or <u>differences</u> in suspect behavior.

Specific hypotheses to be tested are suggested by the mappings, combined with general knowledge

Besides the argumentative influence of the dataset, scientists and lay people of the United States share general knowledge of the country's racial history. From activism and news reporting one can surmise that racial hatred, while by no means universal, is pervasive and those in power, certainly the white police, may tend to brutalize black suspects. Police behavior and race are issues followed closely by the media. People see marked variation in the outcome variable, police violence, in dealing with different racial groups.

Dataset metaphor and initial observations

Thus framed, one's attention focuses on the tabulations of average amounts or percentages of violent acts by police towards whites, blacks, and other groups. These simple tabulations strongly impact macroscopic perceptions of police behavior. What was actually found surprised just about everyone, namely, that black suspects were slightly less likely (but not to a statistically significant degree) to be shot by police compared to other races. These tabulations are considered the "raw data" for the outcome variable and termed "stylized facts".[5]

Dataset metaphor leaves important questions unanswered

Metaphoric mappings of the SOCIAL PROCESS IS DATASET metaphor, even when they seem confirmed by observation, aren't always persuasive. The findings contradicted deeply-held beliefs and many people remained unconvinced by the science. Besides those familiar with the "ecological fallacy", the everyday truism that "statistics lie" fed skepticism that the simple tabulations just discussed produce valid conclusions.

Correlated variables capable of obscuring results

A major limitation of the findings so far was recognized in terms of dataset structure, namely, that aggregated data will mix together the influence of diverse variables, confounding the statistics and obscuring subtle differences in outcomes. Race might co-vary with other factors not included in the dataset, and one or more of these correlated variables could even more plausibly be the cause of police violence. For example, the suspect being armed or aggressive or the encounter occurring at night or in a relatively lawless part of the city might be causative. Data on more variables was needed.

5. Economists use this term when rates are very consistent over time and over varying conditions, so that they are accepted as truth.

In fact, official data existed that, if properly organized, coded, and analyzed, should go beyond the "stylized facts" by taking advantage of another feature of datasets – statistical control – that allows selected sources of variance to be isolated in an effort to clarify questions about police violence in dealing with different racial groups. The research strategy at this point, therefore, was to include these additional variables in the dataset and proceed with enhanced statistical analysis.

More observational data to help uncover a link between race and police violence
Results of this research strategy were reported in a recent study of racial differences in police use of force by Fryer (2016). It was based on data from thousands of police-citizen encounters in several cities. Although video footage of some police-citizen interactions may be viewed, as before, the social situations being studied scientifically are reduced to data coded in terms of pre-defined, police-recorded attributes.

2.4 A metaphor modification and extension: *ceteris paribus*

The dataset metaphor as used so far needed to do more. It wasn't replaced but was pressed to greater service by extending it. This involved adding more variables and more cases. Fryer's research was central to this scientific effort. He doubled down on it by coding from available data more attributes descriptive of police-suspect encounters that might capture features that characterize the encounters or influence their dynamics. The attributes added to the dataset included suspected offense, race of suspect, date, time, place, use of lethal and non-lethal force by police, presence of firearms, duration of encounter, and various categories of peaceful, aggressive or violent acts and verbalization. This extended the research and the SOCIAL PROCESS IS DATASET metaphor.

(5) …65 pre-determined variables in six categories: (A) suspect characteristics, (B) suspect weapon(s), (C) officer characteristics, (D) officer response reason, (E) other encounter characteristics, and (F) location characteristics.

How to make "all things equal"
To gauge the influence of these variables, statistical manipulations are performed that isolate and remove the variance attributable to them. Such statistical manipulations are purported to show results "as if all things are equal" (*ceteris paribus*), to simulate a situation where the interference of all extraneous variables is nullified, making the causal relationship between the key variable (race) and outcome variable (police violence) stand out clearly.

Once this is done it is possible to see if race alone continues to be correlated with police violence. A positive correlation, though no proof of causation, is more justifiably interpreted as such once the influence of the other variables has been removed. That is, if the race variable retains its correlation with police violence when all other variables are statistically held constant, this means that race is not a proxy for something else; race may therefore be considered to lead to police violence all by itself.

These manipulations vastly complicate the statistical techniques. Understanding these complications occupies the attention of scientists and their specialist readers, implying that to comprehend the statistics *is* to comprehend the social phenomenon. Social scientists often recognize how precarious these techniques are and that they thwart straightforward interpretations, but overall their statements foresee readers' forbearance and general acceptance of the approach. Their words evidence the dataset metaphor in operation as a conceptual convention and indicate its dominance in scientists' construal of their activities, even when hedging its interpretation:

(6) "We caution against a causal interpretation of the coefficients on the covariates, which are better viewed as proxies for a broad set of environmental and behavioral factors at the time of an incident."
(Fryer, 2016, p. 20)

'Helper' metaphors: CONTROL *and* PARTITION

But other metaphors are detected that may supplement this understanding. Where the "helper" metaphor more often is introduced to help learners or lay people understand complexities in science, the statistical machinations just described can be conceptually challenging even for specialists. The analytic procedures purport to isolate and remove the influence of real life factors from social interaction. Taken literally, this is mind-bending – on the order of biting an apple but somehow removing the sweetness in order to taste the "appleness". If the procedure were understood metaphorically as removing obstacles on the way to understanding, clearing one's line of vision to see better, or filtering contaminants from food, this might help. But there is no language found in the corpus to suggest such metaphors. Instead, where this dataset analytic approach is discussed, the extension of the dataset metaphor to include sub-mappings of "controls" and the "separating" out of confounding variables is illustrated lexically here:

(7) [results] adjusted for suspect behavior and other factors

(8) Adding precinct and year fixed effects, which estimates racial differences in police use of force by restricting to variation within a given police precinct in a given year

(9) we find no racial differences in either the raw data or when contextual factors are taken into account

(10) Adding controls for demographic and encounter characteristics

(11) Partitioning the data in myriad ways, we find no evidence of racial discrimination in officer-involved shootings

(12) [putting] Differences in quantitative magnitudes aside

(13) investigate the fraction of white and black suspects, separately, who are armed

(14) Panel B describes encounter characteristics for the full sample and then separately by race

"Controls" is a technical term for factors the variance of which is removed statistically, but it seems to retain metaphoricity by implying intent to direct the analyses of an observational study in a way resembling the use of "control groups" in an experimental study. "Partitioning," "separating," "putting aside," "taking account" is physical manipulation to express metaphorically how the social scientist tries to rid the analyses of confounding effects. ("All things being equal," "other variables held constant" or similar phrases are not found in the corpus; I employ them here because they are common in statistics texts and dictionaries.)

Results of extended dataset analysis appear in reports

The results of this further analysis are – with all other factors being equal – that police shootings of suspects are rare as expected. But not at all as expected (yet corresponding to the "stylized facts" from raw data as described earlier) black suspects were shot slightly less often than whites. Non-lethal police violence towards black suspects (such as pushing, throwing to the ground, use of handcuffs, batons, tasers or pepper spray), however, was significantly more frequent than towards other racial groups.[6]

Metaphoric confusion

Understanding of these results depends heavily on the dataset metaphor, and my review shows that it communicates effectively with a public for whom datasets are conventional; it leads one's thinking in certain helpful directions. But it is ultimately confusing, leaving the non-specialist to try to understand an abstract discussion and highly technical mathematical statistics. Specialists and non-specialists alike

6. Scholars reacted to Fryer's unexpected results with methodological criticisms, but did not challenge the dataset approach (which is nearly universally accepted; e.g. Feldman, 2016).

are asked to accept that the dataset adequately represents the social encounters being studied. Further, by accepting the variance-nullifying statistical manipulations, they must imagine a situation even more divorced from reality, where race and only race has an effect on the outcome.[7]

Is there another way to understand the results? The rational investment metaphor

If the evidence does not indicate that the race of the suspect causes police to use lethal force, and indicates only some racial bias in the use of non-lethal force, to what extent may we conclude that police therefore use force primarily for good reason? This invokes investment economics as a metaphor to insert useful terminology and, ostensibly, to aid understanding: CHOICES IN SOCIAL ENCOUNTER ARE COST VS. BENEFIT EVALUATIONS.

(15) the <u>patterns in the data are consistent with a model</u> in which police officers are <u>utility</u> <u>maximizers</u>

(16) the <u>net benefit of investment</u> in compliance is <u>lower for blacks relative to whites</u>.

(17) a <u>fraction of which</u> have a preference for discrimination, who <u>incur relatively high expected costs</u> of officer-involved shootings

This metaphor is imbedded in the rational choice model in sociology and behavioral economics (also known as the rational actor model): entirely rational people doing what is best for themselves in their social context, acting in their own best interests regarding their goals and the means for reaching those goals, looking ahead and making mental calculations to find least costs, highest payoffs or greatest satisfaction. As applied to the questions posed here, rational choice theory postulates that both the police and suspects will maximize the utility of their actions – that is, satisfy legitimate needs while minimizing their risks. (Scott, 2012; for discussion of rational choice theory in the context of several other theories, see Eck & Weisburd, 1995). This corresponds closely to criteria used in court decisions: the question to be answered when judging alleged violent police behavior in court is, did the police do what reasonable people would do under the circumstances?

7. There is no such actual encounter where these other factors are absent. "Nobody ever was or ever will be in a position to observe … *ceteris paribus*." (Rothbard, 2011).

Dataset metaphor leaves questions unanswered
This conclusion asserts rational choice in how the social encounters work, but this is not substantiated by scientific observations as captured by variables in the dataset, nor by characteristics of the dataset; it seems simply the default interpretation after the race hypothesis was largely disconfirmed. This conclusion may contribute somehow to the contemporary political debate about police violence, but is of little value to social science besides as an exceedingly elaborate demonstration of methodology and statistical virtuosity.

It is no wonder that journalists (Bui & Cox, 2016) describe Fryer's results in ways that explain neither what happened in various police-suspect encounters nor how the statistics of a dataset work; the following extracts show some of the mappings discussed already, but mainly they simply say what the data are.

(18) Surprising new evidence shows bias in police use of force but not in shootings

(19) Mr. Fryer found that in such situations, officers …were about 20 percent less likely to shoot if the suspects were black. This estimate was not precise, and firmer conclusions would require more data. But in various models controlling for different factors and using different definitions of tense situations, Mr. Fryer found that blacks were either less likely to be shot or there was no difference between blacks and whites.

Leaving important questions unanswered the dataset metaphor is challenged
Even the Herculean data-collection and analysis efforts described are not capable of capturing essential features of these critical police-citizen encounters. One wonders how the back-and-forth interaction of some police and some suspects actually result in shootings while others do not. Anecdotes of individual cases seem to vary widely, though their data points may be identical. The idiosyncratic dynamics of interpersonal behavior are implicated but remain unaccounted for. For example, how does training of police influence an encounter? Had they formed de-escalation habits? And did they use them? What was the level of fear in each party, and how was it expressed? To what extent did the individuals try to project reputations for toughness?

3. The social field metaphor in the study of social conflict in fraught and volatile encounters

Generally speaking, social behavior, including the decisions made and actions taken by police and citizens in an encounter, is influenced by many internal and external factors and may include the entire spectrum of past and present experience. The encounter can be regarded as a multifaceted dynamic process. Scientists, students and others can be expected to want to know something about this process and how to find out more.

An understanding of social interaction, including alleged criminal behavior, is reflected when a properly constituted court of law hears an individual case. In court, rich detail is presented about the accused person and police officers, the alleged offense, the circumstances, along with a detailed testimony of what happened in the given police-suspect encounter. Both the more proximate, fast-changing, choice-relevant situational factors are considered, as well as long-lasting, time-stable individual differences.

A scientist who might attempt to take all such factors and dynamics into account for multiple cases would need clear theoretical guidance on what to observe and when, knowing that some of the most important factors (such as political power or social pressure) may not be readily quantifiable and must be derived qualitatively from patterns in events.

The discussion just completed above where the dataset metaphor is dominant resulted in interesting findings but leaves important questions unanswered. It is an account of empirical social science that uses after-the-fact third-party coding of predefined, surface attributes of each case. While most investigators continue to refine their datasets and methods of tabulation and analysis, other social scientists, though relatively few in number, take a different view of social conflict situations such as the police-suspect encounter. To discuss this I will use the same outline of scientific metaphor *métier* or vocation as already described to explore how metaphors structure thinking, their usefulness to scientists and laypeople, as well as how metaphors change.

3.1 Social field theory

Social field theory is the name given to theories originally propounded by Kurt Lewin (1951) and Pierre Bourdieu (1985). Such theories consider social situations with more of the broad sweep of proximate and distal influences, specifics of an encounter and its context. This portrays a web of forces that interact dynamically to move persons in a metaphoric space, towards or away from specific states or actions; when a multiplicity of these forces accord with each other the resulting thought or action will seem to be goal-directed; lack of accord may be interpreted as ambivalence, disorganization or even derangement (Vallacher et al., 2015). Furthermore, social field theory looks at sequences of events, thoughts and behavior and how they may or may not align at all relevant levels, such as personal, small group, institution, and culture, and how all these factors interact and change each other over time. This potentially makes very complex social phenomena more intuitive and accessible (Martin, 2003).

Social field theory is the antithesis of "substance ontology" (Seibt, 2008, mentioned above) because the field is a matrix of entities (variously described as forces, perceptions, positions, resources) that has no mass and takes up no space, operates forcefully at close range or at considerable distance with no direct or indirect contact, and causes change without motion or mechanism; field theory seems to follow the spatial logic of fluid dynamics (Martin, 2003) – but there is no fluid. From this, and to some extent from that of gravity, magnetism, and electricity, is conceived multiple forces interacting over time, producing a variety of effects.

Ideally, field theory depicts a dynamically moving picture of fraught or volatile social interactions – a qualitative, processule rendition – in contrast to the snap-shot approach of quantifying a small number of static variables. When they theorize, field theorists offer a holistic approach that generally promises a full and complete accounting of the social field. Furthermore, they want to include fine-grained psychological functioning, such as habits developed through childhood and school, peer group socialization, and in general the life one lives. Field theorists particularly want to know how people change position in their social matrix, how they think and act at various points in time.

The idealized social field

In describing social field theory it is important to keep in mind that this is its ideal form – what field theorists might conceive in their wildest dreams. The absence of a corpuscular or mechanical medium to transmit forces, while at first seeming almost supernatural, relieves the social scientist from counter-intuitive claims about primary causes or the effects of a factor with all else held constant. The field metaphor offers a naturalistic, multivariate, contextually situated, everything-affects-everything process unfolding over time. Even fixed principles such as laws, rules and practices are situationally applied, accounting for patterns of both conformity and non-conformity. Note that the dataset metaphor is reliant on large numbers of cases and central-tendency statistics, that are presumed to show lawful regularities, so it is inconclusive about cases that deviate from the mean. "Field theory, in contrast, emphasizes that the regularity comes at the level of the situation and that the further one goes into a particular case, the more revealing it will be of general principles." (Martin, 2003 p. 35). Field theory clarifies general understanding by delving into the qualitative aspects of individual cases.

Consequently, causation, as conceived when the dataset metaphor is dominant and the researcher attempts to isolate causation to one or a few independent variables (see previous section), is de-emphasized or disappears altogether. It is replaced by *explanation*: a social phenomenon is explained when the interacting elements of the social field in which it occurs, and the elements of layered or linked fields, are interpretable, their alignments (or lack thereof) are made plain and are understood (cf. Martin 2003, p. 44). This evokes the idea of "causal texture" (Tolman & Brunswik, 1935) or a causal whole, encompassing both people and their environment, that allows particular behavior or action to happen. The desired result would be to comprehend the personal and social conditions, together with organizational structure, that produce optimum police-suspect interactions. I propose a conceptual metaphor that underlies these theoretical considerations, stated as SOCIAL PROCESS IS FIELD OF FORCES WITH PARTICULAR POWER AND DIRECTION (shortened to SOCIAL PROCESS IS FIELD OF FORCES).

3.2 Application of the social field metaphor

Sub-mappings of the social field metaphor suggest how scientists' perspectives are shifted.

Social field of elements with power and direction

The conceptual metaphor SOCIAL PROCESS IS FIELD OF FORCES broadens the scientist's view. As any metaphor does, it backgrounds certain issues, and shifts perspective to highlight others in complex interaction. Where the dataset metaphor plays up questions of categorical prediction – does race lead to police violence? – the social field metaphor emphasizes the entirety of a social process – how does police-suspect conflict unfold or how might it be managed? With the social field metaphor operating, the unique effect of a suspect's race on police violence attracts much less attention. The field metaphor renders a police-suspect encounter with so many salient factors interacting over time that attention is drawn to the rapid changes occurring in even very short-duration encounters; it renders a process of give-and-take with many opportunities to change course.

The image schema of "field" includes a multitude of personal, organizational or cultural influences such as persons, social units, or social structures that have various degrees of intensity or (non-physical) power depending on their assets. Assets are conceived metaphorically as objects or entities each of which has a valence, force, or source of directed power (such assets are labeled by Bourdieu as "capital"; note the affinity for understanding sociology metaphorically as investment economics). The field is the net result of the many valences pulling and pushing in particular directions (Martin, 2003).

Sub-mapping – POSITION

Points or positions in the rich and comprehensive, hyper-dimensional social field are reduced to two- or three-dimensions. Each person, social unit, and social structure is metaphorically understood as a point on a field or terrain. Their relative positions on the terrain are mapped to differences in their origins, circumstances, local or mutual interactions. The proximity to others represents similarities among them. Language in the following extracts shows the operation of the POSITION sub-mapping.

(20) social background, career, military education, generation, age and so on, form the basis for analysis of the social field where the officers are positioned … concerning the officer's standpoints and positions

(21) Field: a system of relations between positions

(22) a system of dispositions that effect how people act, think and orient in the social world

Sub-mapping – POWER

The SOCIAL PROCESS IS FIELD OF FORCES metaphor, to review the description so far, invokes the notion of field or terrain, upon which are a number of entities that, in turn, are mapped to persons, social units, or social structures. Each of these possesses force or power (derived from assets as described above) the Newtonian force-mechanics interpretation of which is discouraged by field theorists' substitution of the word "valence." This is mapped to intensity and direction, further discussed below. The overall field is mapped to the net result of the many valences pulling and pushing (Martin, 2003).

The metaphoric mappings often show how certain qualitative and dynamic aspects of field theory in its idealized form trade off with the well-established quantitative characteristics of the dataset metaphor. Even as researchers who have adopted field theory proclaim their ideal – the absence of a corpuscular or mechanical medium to transmit force in Newtonian fashion – their language in the extracts below invokes force mechanics nonetheless as it shows the operation of the POWER sub-mapping:

(23) the power that state or non-state actors have … imputing great strength

(24) Social capital [assets]: relatives, friends, associations, memberships, relations etc.

(25) Cultural capital [assets]: cultivated language, noblesse … seen as a sub-part of the more general notion of "symbolic capital"

(26) Economic capital: material assets and knowledge of the rules of economy

Sub-mapping – DIRECTION
Valences (forces) have direction, and the various entities' valences align or misalign in diverse ways; this maps to support or interference with each other as they interact. If the topic or target of interest here is police behavior, the valences are conceived to be directed towards, and have a net controlling influence or effect on, what police officers do as they encounter a crime suspect, how they might then move along trajectories to future positions.

(27) the people towards whom the change is directed

(28) crime and crime control became central within the political and social arenas

(29) control through the criminal justice system as well as medical and psychological facilities, which are directed towards individual police officers

Sub-mapping – SEMI-AUTONOMOUS FIELDS
Semi-autonomous fields are metaphorically understood as physical layers – an organized physical structure or system with various levels. Even though what is within the bounds of each level and how it is organized is independently determined, the layers provide some kind of mutual support and stability. In social field theory this maps to two or more social field terrains and within the boundaries of each are certain independently determined customs and rules. The levels relate to each other hierarchically from macroscopic/general to microscopic/specific.[8] These excerpts exemplify the use of certain terms and suggest how the SEMI-AUTONOMOUS FIELD conceptual metaphor operates:

(30) semi-autonomous fields are defined by their boundaries and ability to create rules or induce compliance to them

(31) These social systems create rules, customs and symbols, and are simultaneously influenced by external rules, decisions and forces

(32) understanding how police officers, who belong to particular social fields, comply with and resist

To what extent do social field theory metaphors guide observations?
The SOCIAL FIELD metaphor, and its sub-mappings of POSITION, DIRECTION, POWER, and SEMI-AUTONOMOUS FIELDS, are capable of guiding investigations and

8. The overall structure of fields is mapped to overall structure of behaviors in Bourdieu's idea of "Habitus" (Latinized 'habit', dictionary definition: general constitution, especially physical build).

suggesting hypotheses. I was not able to find examples in the literature of social field theory applied specifically to investigate violence in police-suspect encounters. But I have found field theory scholarship, as applied to the use of legitimate force to coerce compliance, focusing most often not on incidence of violence, but on reform of police and military institutions in ways that properly regulate such force; such texts form the corpus for this section (see Appendix 1). These applications of social field theory offer in-depth understanding of police and military planning and of reform of these complex social systems, particularly social conflict as it arises in such reform projects. Social field theory is well suited to comprehend change from previous patterns. For scientists it is generative in the sense that it prompts investigators to consider multiple standpoints, including objective perspectives simultaneously with subjective ones. Students and the lay public can then be given a bigger picture than the recitation of statistics would portray.

Some evidence of the afterlife of dataset metaphor

To test hypotheses generated by the social field metaphor, the researcher tries to characterize all relevant fields, capture organizational characteristics and the perceptions of the people involved. To do this, observations are performed, along with interviews and even focus groups, to apprehend individual and group norms, attitudes, beliefs, values, goals, and behavior. It is daunting to take full account of all social field information as it emerges over the relevant time period for the cases involved.

This practical reality impacts research strategies in the use of social field theory. The requisite amounts of time and other resources can be prohibitive. Additionally, the strong mandate in science to quantify and predict, will influence field scientists' priorities. So the field theory researcher may be obliged to put the information gathered into the form of a dataset, a well-known research tool as discussed in the previous section. Unavoidably the dataset metaphor is reincarnated, coexisting with metaphors indigenous to social field theory.

Possible metaphoric contradiction

In describing their methods for apprehending the social field under study, the scientists' language (see excerpts below) gives evidence of the social field metaphor as expected. But some investigators also give lists of psychosocial traits and states to be measured. This suggests that they may be planning to collect coded data that can be plugged into a dataset. Others overtly refer to such a dataset. This can implicitly undermine field theory's more inclusive purview and invoke the physical force causation metaphor described in the previous section.

(33) researchers have relied on qualitative methods …to capture the nuances of organisational norms and values,

(34) framework of cultural knowledge within organisations … important factors are public perception of the police, crime and violence levels, feelings of insecurity …

(35) To understand the …social climate, objective characteristics …must be measured

(36) The aim of the study has been to create an empirical data base

'Helper' metaphors

A metaphor found in social field theory scholarship that is to assist understanding, although it may oversimplify, is the dramaturgical metaphor, ROLE, along with some of its conventional sub-mappings, such as a learned sequence, manner of acting, individual subjective experience, fulfilling a function, responding to demands from outside:

(37) the role considered to be core skills, cognitions and affect … It includes, accepted practices, rules and principles of conduct that are situationally applied, and generalised rationales and beliefs. In other words, it is the manner in which police officers' chiefs and colleagues expect law enforcement officials to conduct their work.

(38) these actors and their continuous involvement play a crucial role in …

Another "helper" metaphor is that of the GAME (social, not game theory), which organizes understanding of a field and how it works using conventionalized sub-mappings such as competition, rules, fairness, prize-winning, object of game.

(39) [game captures] the field's ability to provide goals while being a site of conflict

(40) fields differ from board games, however, in that the struggle is both over and within the rules

(41) alignments between actors oriented to related prizes

The social field theory metaphor is retained for certain uses

Social field theory inspires many researchers with a promise of understanding the entire social field. Unfortunately most researchers do not undertake (no doubt could not find the resources to undertake) the sweeping and inclusive investigations that the theory seems to call for, but instead tend to reduce how they represent the social field to small combinations of factors. In that way the promise of social field theory is not fulfilled.

While social field theory posits large numbers of interacting factors and a multi-level structure ranging from macroscopic generality to microscopic specificity, it resists the formalization required to empirically predict specific outcomes. Since the formalization is lacking, the theory, underpinned by metaphors as described above, succeeds in offering big-picture perspective, but fails to provide the kind of predictive power that can be reduced to a formula or that might ultimately be considered lawful. The FIELD metaphor with its sub-mappings of POSITION, POWER, DIRECTION, and SEMI-AUTONOMOUS LEVELS re-purposes existing terminology and communicates specific meaning, making it more cognitively useful. But even with help from these metaphors, the theory has thus far generated few clear or specific hypotheses as to how field elements interact over time to produce such macro events as occur in fraught or volatile social encounters.

Field theory metaphors leave important questions unanswered
Social field theory research, producing broad understanding and eschewing clear prescriptions for policy initiatives, leaves questions unanswered. Governmental authorities and scientific funding agencies often want more specific guidance than is provided by the general understanding and explanations of social field theory. Because it has fallen short in this way different tools might be needed to unlock its potential, which may include computer simulation modeling. Lewin and Bourdieu had no access to these tools and so perhaps their theories had to wait until such methods had been sufficiently developed.

4. The adaptive dynamical systems metaphor in the study of fraught and volatile social encounters

Challenge to other metaphors. Both the dataset metaphor and its approach, and the social field metaphor with its approach, seemed ineffectual in accounting for an event such as police violence in encounters with crime suspects. Reasons are numerous, but one that stands out is the assumption common to both the dataset and social field theory approaches, that outcomes are linearly related to independent variables, and this is always likely to fail:

> Despite the assumption of linear causality embedded in the last 400 years of science, it is almost impossible to predict specific outcomes in any nonlinear social system; their dynamics are too complex… However, *general patterns* of thoughts, feelings, actions, and so on can be determined.
>
> (Vallacher et al. 2015, p. 77, emphasis added)

4.1 Basic form of dynamical systems metaphor and its application

To better predict and explain the higher-order event (the outcome of a tense social process) social scientists are motivated to look for another approach. Violence escalates, for example, in only some cases or seems to appear spontaneously, idiosyncratically, almost by accident. Of perhaps greater importance are the equally unpredictable instances of calm, acquiescence or collaboration that characterize the non-violent cases.

Adaptive dynamical systems theory had already been developed to address non-linear dynamics, instability, sudden changes, over- and under-response, and chaotic tendencies in physical sciences such as astronomy and meteorology. Its usefulness in these and other complex fields was noticed by some social scientists. Having been primed by social field theory to consider the social matrix of interacting elements (as discussed in the previous section), some social scientists were able to re-conceptualize the encounters as part of an adaptive dynamical system.

The dynamical systems approach shares with social field theory the notion that social process is a FIELD OF FORCES, in two or more layers. As in social field theory, the field and its layered composition are not directly observable as such, but their metaphoric structures are mapped to observable phenomena.

The layers are ordered HIERARCHICALLY and range from macroscopic, or more abstract elements (interpersonal, group or societal interactions), to microscopic, or more concrete elements (individual thoughts, feelings, behavior). This multilevel field corresponds with conventional ideas of hierarchy in social psychology (Lawler, Ridgeway & Markovsky, 1993). By incorporating these figurative elements a complex of integrated elements interacting over time is invoked. It is a simple step to propose a conceptual metaphor for the fraught or violent social process stated as SOCIAL ENCOUNTER IS ADAPTIVE DYNAMICAL SYSTEM.

4.2 The adaptive dynamical system metaphor and its sub-mappings

This metaphor is considered in terms of three sub-mappings: LEVELS AND TIME, LINEAR AND NON-LINEAR MOVEMENT, and EQUILIBRIUM. These are necessary and specific characteristics integral to the operation of adaptive dynamical systems and some, in turn, have additional metaphoric sub-mappings operating within them.

The sub-mapping of LEVELS AND TIME

In contrast to the dataset or field theory approaches, the dynamical systems approach prompts the scientist to consider the macro level of the social scientist's interest – the societal level of interpersonal or group behavior, together with the micro level – the internal psychological processes of the individual. (Other intermediate levels might also be identified but none are discussed here.)

Dynamical systems theory postulates a degree of independence and autonomous ordering of elements within each level such that the activity within a level coalesces and organizes itself. Sometimes, but not always, this gives rise to surprising patterns at another level that are not reducible to this self-organization. The exact form of such organization at one level, or how it gives rise to new patterns at another level, are not directly observable.

Unexpected macro level outcomes, that may occur due to non-linear relationships, are said to *emerge*. This word is used in the sense of a shoot that emerges from a seed, or a rainbow emerging after a storm. Violence in police-suspect encounters can be considered as a phenomenon that emerges from a mix of factors interacting in a non-linear fashion. This suggests another metaphoric mapping that might be stated as EMERGENCE IS APPEARANCE OF IRREDUCIBLE NEW PATTERN. It asks how the organization at each level develops over time and influences organization at other levels.[9]

(42) visualize the emergence of social structures due to dynamic processes

(43) higher-level properties and behaviors emerge from the internal workings of the system, the process is commonly referred to as self-organization

The concept of emergence is named and minimally described, using conceptually limited language in these excerpts.

Mapping LEVELS AND TIME *to observations*

For purposes here, the macro level is mapped, for parties to a fraught or volatile social encounter, to their mutual interaction and the micro level is mapped to psychological dynamics – what each individual may be thinking, feeling, or processing internally.

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9. The metaphor suggested by the word "emergence" comes from its dictionary meanings: something that appears, comes into view, unfolds, issues forth, arises, becomes known, or becomes important; and from mappings of the underlying metaphors of vision, procreation, or the contents coming out of a container. While adding color, these figurative meanings have little generative effect. The semantic richness in *emergence* is lost and, as a metaphor, it can be said to be closed. It has introduced a useful term the practical, literal understanding of which depends on its definition in complexity science: emergence is a higher-order property or behavior that comes about from the complex interactions of lower-order elements, but which cannot be reduced or ascribed to the properties of those elements. (see Christen & Franklin, 2002, for a full explanation of the concept of emergence, its possible roots in vitalism, and relation to reductionism).

The micro level is often neglected in traditional social science, for example, in sociology or behavioral economics; or it is represented by snapshot summaries, one-time attitude assessments, or demographic categories. Psychological dynamics can vary from case to case depending on individual differences, situational factors, and the temporal arrangement of events. Traditional social scientists study large numbers of cases, use central tendency statistics, and expect the variation due to micro level psychological dynamics to cancel out. Dynamical systems investigators, on the other hand, attempt to monitor these processes at both levels, at many points in time, and take these data fully into account.

For the corpus used in this section, lexical evidence appears that some, but not all, of the metaphoric features just mentioned are employed to structure this kind of social science. Investigators are prompted to note how much activity at one level seems connected with change at another. In the following extracts, language is found that invokes a vertical, high-low metaphor (BETTER, STRONGER, MORE IMPORTANT IS HIGHER). It associates high with macro and low with micro, implying that high level or macro properties are of greater importance, yet offering little else about how authors in this corpus think about these levels; the spatial and structural aspects are named but not conceptually elaborated.

(44) functional independence of a system's <u>lower-level</u> elements …promote meaningful changes at the <u>macro level</u>

(45) promotes progressive <u>integration</u> of system elements into a <u>higher order structure</u> … <u>patterns</u> due to the particular confluence of forces at any point in time

(46) properties at a <u>macro level</u> cannot be derived from properties of the system's <u>lower level</u> elements

At this point it is revealing to add the metaphor of time passing on a continuum, which gives a sense of movement and some context for unforeseen activity:

(47) not as a <u>moment-in-time</u>, but rather as a process <u>unfolding</u> in relationships <u>across time</u>

(48) <u>Over time</u>, the initial response may become amplified in intensity, diminished in intensity, or follow a more complex <u>time course</u> such as <u>periodic oscillation</u> or <u>chaos</u>

Because of the conventional, entrenched metaphors TIME IS DISTANCE and CHANGE IS MOVEMENT, the passage of time implies change. Investigators, now primed to ask about changes at both micro and macro levels over an expanse of time, are better attuned to outcomes that seem to occur spontaneously.

Sub-mapping: LINEAR AND NONLINEAR MOVEMENT

How are we to understand these spontaneous outcomes? Dynamical systems are well known to involve non-linear relationships, which are difficult to observe in action or to detect statistically. While the notions of linearity and non-linearity can be applied quite literally when talking specifically about observed psychological dynamics or social behavior, they are applied figuratively as sub-mappings of the FRAUGHT AND VOLATILE SOCIAL ENCOUNTER IS ADAPTIVE DYNAMICAL SYSTEM metaphor. These sub-mappings can have multiple implications, where movement is over a metaphoric system terrain, a dimension of which is time, and which might progress in a straight line, a curve, or in some squiggly form. Metaphoric implications, along with literal ones, are evidenced in corpus examples below. The metaphoric sub-mappings do not help predict when such movement, or its form or direction, might be observed; still the implications alert a researcher to possibilities:

(49) whether a linear or a nonlinear trajectory is observed in conflicts characterized by increasing provocations

(50) the hysteresis [being stuck in recurring pattern] associated with nonlinear systems

(51) Even a slight change … will promote a change in the system's trajectory

(52) momentary thought, feeling, or action represents a punctuation point in a continuous flow of events that interact over time, producing a complex trajectory of points

The notions of linear and non-linear movement in all of its variety suggests that the social field, while sometimes flat, can include curving terrain that may resemble hills and valleys. This metaphoric representation appears in the "helper" metaphor described later.

Initial scientific observations related to LEVELS AND TIME

Dynamical systems research in social science focuses investigators' attention, over the duration of an encounter, on both the macro level of social interaction, and each person's microcosmic, internally generated patterns of emotion and thought. General findings accord with the metaphorically conceived macro-micro distinction, and show the micro patterns to have clear but quite complex influence on macrocosmic outcomes (Vallacher et al., 2015). Later we shall see how this provides opportunities for further observations and interventions in social interaction.

Sub-mapping: EQUILIBRIUM

Not found in the dataset or field theory approach, a basic feature of dynamical systems includes intervals of turbulence usually followed by quiescence, or chaos followed by orderliness; dynamical systems tend to settle into some kind of equipoise that prevails over time. Such an equilibrium may be sustained, or may lapse into escalating instability should a disruptive event occur or someone act provocatively. That is, on the one hand, if micro elements of a system (the emotions, desires, intentions and behavior of parties to the encounter) become volatile or disruptive, dangerous or destructive outcomes can result. On the other hand, if the turbulence is somehow endured, the system eventually slows, reaching a stable or cyclically regular state (cf. homeostasis metaphor in Johnson, 1987).

The dynamical system in equilibrium can be mapped to the social interaction; the metaphor might be identified as SOCIAL DYNAMICS IS QUIET/NOISY MOVEMENT. The dynamics of equilibrium in systems theory evokes the image of ongoing movement that is slow, smooth, quiet, perhaps repetitive, maintaining a kind of balance. On the one hand, small stresses or pushes from outside may disrupt the pattern, making the movement momentarily turbulent; this maps in general to deviation from the norm, irregular action, and in social science to non-cooperation, non-compliance, argument, threats. If the system recalibrates and outside forces dissipate, stability can be restored; this maps to restoration of calm, restraint and compliance.

On the other hand, strong, continuing pushes from outside, perhaps combined with internal weakness from fatigue, can result in loss of this quiet state as the system must make more extensive adaptations and seek some steady state different from the previous one; this maps in general to change in relative position, encroachment, escape, destruction, and in social science to aggression or violence. Below are lexical examples of how social science theorists use this EQUILIBRIUM metaphor when drawing parallels to dynamical phenomena in other scientific domains:

(53) In ecology, the concern is how animals interact to generate and <u>maintain a balance</u> between predator and prey

(54) bodies such as planets and moons influence each other to produce <u>stable</u> orbits

Notice once again the implication of process over time. The metaphor encompasses an entire social encounter; it prompts investigators to observe the system jointly formed by potentially conflicting parties from beginning to end, to look for evidence of balance maintained or lost, oscillations, perturbations, weakening, and different degrees of outside influences over the duration of the encounter. In textual examples given, researchers who have adopted adaptive dynamical systems theory use language that indicate their implicit mapping of LINEAR AND NONLINEAR MOVEMENT and SOCIAL DYNAMICS IS QUIET/NOISY MOVEMENT to the kinds of interaction found between parties in conflict:

(55) display resistance to change in their behavioral options in the face of increasing provocation by the other person, until a threshold was reached, at which time they would switch from a relatively conciliatory behavioral choice to a more aggressive choice

(56) dynamical systems tend to display periods of stability and resistance to change, punctuated by periods of disassembly

(57) an external force may diminish, perhaps rapidly or perhaps slowly, or it may become intensified …the process in question can display different equilibrium tendencies

(58) tends to maintain that state despite forces and influences that have the potential to destabilize it. An external influence may perturb the system and move it to another state, but the system will return fairly quickly

If a disruption or provocation is prolonged or repeated, the system adapts and can self-organize, forming a new equilibrium. This macro level pattern then exerts a "downward causation" that tends to reorganize and limit micro level elements so as to perpetuate the new equilibrium. Sometimes the state of the system will alternate between the two. The notion of "downward causation" is conceptualized metaphorically as an organizational pattern appearing spontaneously and that configures, limits and restrains.

(59) Once a higher-level state emerges by means of self-organization, it constrains the behavior of the [microcosmic] elements that give rise to it

(60) From this disassembled state of affairs, however, the system is primed for self-organization and the emergence of a new higher-order state that provides a different dynamic configuration of the lower-level elements

Metaphor thus far confirmed

Observations of people in conflict largely validate these metaphoric inferences. At the micro level, when the people involved display relatively quiet emotions and deliberate attempts to control their behavior, this is followed at the macro level by acquiescence, giving and following of instructions, and relative calmness. Social science research shows that small perturbations – ones not large enough to disrupt – can heighten activity level to the point that inertia or stagnation is overcome, attention, learning, and creativity occur, and change becomes possible (Vallacher et al., 2015). But if more severe perturbations push individuals out of equilibrium, resulting in prolonged aggressive behavior, participants adapt and cope at this more aggravated level, stimulating and heightening micro level emotions and actions needed for fight or flight; this may continue to a violent conclusion.

Metaphor usefulness: Questions posed that lead to dynamical interpretation of psychological experiments

Most psychological experimentation reported in the academic literature is not carried out from a dynamical systems perspective but uses a model such as group conformity or rational choice. For example, the rational choice model predicts proportional response to stimuli (a linear function of provocation) – if subjects are provoked mildly, a rational response would be relatively mild, compared to when provoked strongly, when the response is expected to be stronger. Yet results often show unexplained non-proportionate (nonlinear) responses.

Reasoning from the adaptive dynamical systems source domain, what conditions might investigators look for that would explain when responses are proportionate vs. non-proportionate, that is, over-reaction, under-reaction, or proportionate responses to strong perturbations? Reasoning from this metaphor, to the degree that cognitive dynamics are well-established and integrated, the individual's cognitive trajectory will be more stable and predictable. This strengthens the equilibrium state in the face of threatening perturbations, leading us to expect more carefully regulated and linearly proportionate responses. If, on the other hand, one's cognitive dynamics are minimally structured, the trajectory may diverge.

This accords with findings: For example, it has been shown that bringing a person's conscious attention to micro-level behavior (his or her own internal dynamics) will predispose one to accept macro-level explanations or justifications (Vallacher et al., 2015). The dynamical systems metaphor suggests that self-reflection on one's own processes will reinforce and stabilize cognitive structure, perhaps by activating feedback loops. Positive and negative feedback loops reinforce each other progressively and are thought to be integral to adaptation and self-organization. More and varied feedback loops are known to strengthen integration of the overall system. An equilibrium that results might be expected to be more resistant to perturbations. As already shown above, in language used by systems theorists, some of this reasoning can be detected:

(61) whether a <u>linear</u> or a <u>nonlinear trajectory</u> is observed in conflicts characterized by increasing provocations

However, experiments indicate a possible interaction with one's generalized need for closure (intolerance of ambiguity, complexity, nuance, and uncertainty; see

Kruglanski & Webster, 1996). Individuals impatient for closure are found more likely to over-respond (respond non-linearly) to perceived uncertainty or threat. Those with low need for closure, on the other hand, tolerate ambiguity and respond more proportionately (linearly), and are judged to be more constructive. In describing need for closure, terms are used that might describe conditions of equilibrium in a dynamical system:

(62) [with high need for closure] there is <u>intolerance</u> of nuance and little patience for having all the pertinent facts

(63) [with low need for closure] <u>tolerance</u> of ambiguity, complexity, nuance, and uncertainty

Left to future research is the question of whether tests used to measure need for closure are actually assessing the stability and integration of one's cognitive structure, as suggested by the EQUILIBRIUM and *LINEAR AND NONLINEAR MOVEMENT* sub-mappings.

"Helper" metaphor: ATTRACTORS

So far in this section I have offered the overall metaphor FRAUGHT AND VOLATILE SOCIAL ENCOUNTER IS ADAPTIVE DYNAMICAL SYSTEM and have used several sub-mappings that further describe the social encounter: MULTI-LEVEL MACRO–MICRO STRUCTURE, TIME, LINEAR AND NONLINEAR MOVEMENT, and EQUILIBRIUM, including other semantically rich notions such as system perturbation, emergence, self-organization, and trajectory.

Together, these mappings offer a useful semantic network. Additional help in thinking about this complexity comes from another metaphor used by systems theorists, a notion that largely summarizes those just listed, known as ATTRACTORS. I am suggesting the conceptual metaphor SOCIAL ENCOUNTER IS A BALL ROLLING ON ATTRACTOR TERRAIN. I term this a "helper" metaphor because it helps one think readily of the entire subject matter in a relatively coherent way; but one can see that the sub-mappings, if followed too closely, are epistemologically troubling. Here is a description, with sub-mappings indicated (see Figure 1):

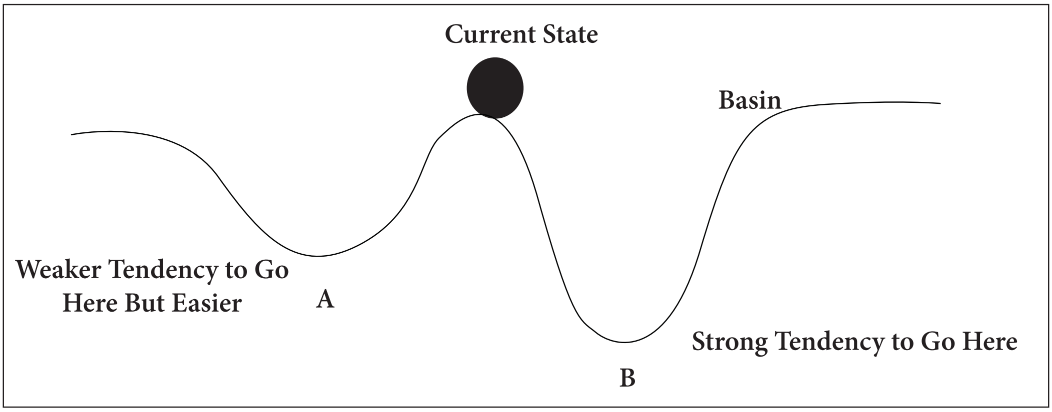

Figure 1. Dynamical system with two attractors (A and B)

Mapping "helper" metaphor to observations

A dynamical system moves on its landscape like a ball might move on a hilly surface that includes flat and inclined areas and distinct basins. The ball maps to the system's (the social encounter's) current macro state (such as calm, assertive, violent); the distance traveled maps to successive points in time; the landscape with its hills and valleys maps to micro conditions as encountered over time. These mappings suggest that one think of the macro or current state of the system (mutual behavior of police and suspect) as something that can move/roll/travel (that is, change), entering or leaving distinctive topological regions (types of interaction). With this metaphorical view, the question is, where would it go? This metaphor helps us interpret the kinds of conditions that can lead to psychosocial stabilities, resistances, instabilities and changes in individual cases and aggregate results. So, what factors predispose movement along this trajectory and what alternatives exist for where the system might ultimately come to rest?

Valleys or basins in the landscape (A and B in Figure 1) map to areas of equilibrium. In this example there are two such regions on the landscape, one characterized as forceful, aggressive or violent behavior (B in Figure 1 is easier to enter and more difficult to leave), and the other as relatively peaceful or non-violent behavior (A). A basin exerts the pull of gravity, depending on where the system is currently located, down its walls, and this maps as tendencies to equilibrium.

So some regions seem to attract the system, causing the ball, if it is nearby, to enter the region and stay there and to return should it be pushed out; this maps to how macro patterns of behavior, when repeated, structure and constrain, in the manner of "downward causation", future micro behavioral sequences in the social encounter such that they repeat, resist change, or are difficult to alter.

Multiple basins map to alternative equilibrium states (such as calm compliance or aggressive resistance). The rim of each basin maps to system boundary conditions where volatile turbulence can occur; the slope of the walls maps to ease of entry or exit; the depth maps to the stability of the equilibrium or whether, after small or brief changes, the system will simply return to the same attractor even though others may have been available.

The tendency of dynamical systems to find and move towards an equilibrium creates a trajectory. The trajectory is not only formed by internal factors metaphorically understood as the hills and valleys of the terrain, but also by external influences that change system state (such as the sound of gunfire that might provoke momentary police assertiveness or suspect resistance, aggressive goading, bystander/mob intervention, severe weather or, on the other hand, assurances of safety). These influences propel the system in one direction or another, and with sufficient force alter the trajectory by overcoming the effect of gravity and contours of the terrain. This could push/escalate the system out of its current non-violent attractor basin (A in Figure 1). If the external force is of short duration, energy dissipates, and if the basin is wide enough and the slope steep enough, the system tends to return to the attractor after disruption. If it is of longer duration or greater force, it could push the system into another attractor (B in Figure 1), corresponding to escalation involving high aggression or fighting.

This metaphor and its various features are detected in the language of systems theorists when they are speaking about ATTRACTOR dynamics.

(64) An artificial gravity relentlessly pulls those participants downhill into a valley

(65) The location in that landscape represents some characteristic of the conflict, for example, the emotional states of the participants

(66) conflict acts like a gravity well into which the surrounding mental, behavioral, and social-structural landscape begins to slide

(67) the system … can escape … and settle in [another attractor] … if enough force is employed to move the ball up the hill and into the valley

(68) lasting changes in the state of the system, meanwhile, correspond to changes in the structure of attractors

(69) negative events and interactions may fail to disrupt peaceful relations but gradually create and deepen a latent negative attractor

(70) the positive attractor loses its stability and the relationship abruptly moves to the extreme values defined by the negative attractor

(71) promote a large change in the system's trajectory if this change represents a state that falls just outside the original basin of attraction and within a basin for a different attractor

(72) Each element can be stimulated and perpetuated along its current path through reinforcing feedback loops between elements, where one element stimulates another along its current trajectory and this element, in turn, stimulates the first – thus making a loop.

(73) Escape out of the valley, and therefore out of the conflict, is possible only if additional forces or a change in behavior get the participants past the top ridge that forms the valley, or a deeper more favorable valley opens up within their reach.

Computer applications that depict systems as shown in Figure 1 allow the user to watch the results of system dynamics over time and to experiment by altering internal and external influences (Vallacher et al., 2015); this can provide new grounding for the dynamical systems metaphor that consolidates complicated verbal descriptions such as appear above. Exposing people to systems concepts has been shown to induce a systems-thinking mindset (Thibodeau et al., 2016).

Epistemological confusion likely

As a "helper," the attractor metaphor facilitates rapid appreciation of dynamical systems, and generates scientific and practical ideas. But students should be aware that it contains errors in what it teaches.

The account given by attractor dynamics neatly depicts a system stabilizing as a ball rolls into a depression, or attractor. This metaphorically substitutes movement for change, space for time, rest for stability, and gravity for force or propulsion – portraying a comprehensive and lucid dynamic. However, what has been learned from this metaphoric depiction about the complexity of the state of the system, the processes of dynamical interaction, adaptation, feedback, and self-organization that operate over time? All of these are backgrounded by the rolling ball metaphor. This metaphor explains little about the internal and external sources and flows of force or energy, activation of feedback loops or how attractors are formed and changed when these are depicted metaphorically as the simple pull of gravity (Smith, 2015).

4.3 Metaphor retention: Usefulness in posing questions and in assisting practical applications

How a dynamical system works is known in detail from the results in solving differential equations or running computer simulations. Such systems possess distinct features not found in the dataset approach or social field theory. As has been described above, the theory and many of its metaphorical aspects have generated helpful social science hypotheses. Because there are so many factors in a system interacting in a multiplicity of ways, empirical scientific investigation understandably proceeds step by step. Observational and experimental studies of various conflictual social encounters largely support the mappings as described above, and computer simulations demonstrate dynamical system behavior conceptualized as attractor dynamics. Notwithstanding certain cautions as mentioned, these results argue for retention of the metaphor in studying social processes.

The FRAUGHT AND VOLATILE SOCIAL ENCOUNTER IS ADAPTIVE DYNAMICAL SYSTEM metaphor, with its sub-mappings, is promising as a pedagogical tool, particularly for students already familiar with the mathematical and computational means of investigating dynamical systems. For the general public, the ATTRACTOR as a "helper" metaphor offers access to what might initially appear daunting; it can be found in popular accounts of such topics as fractal images and brain science. An additional argument for retention of the metaphor comes from its possible practical applications, for example, in training those who actually deal with intense conflict. To the degree such training is found effective in shifting perspective and conceptualizing situations accordingly, trainees may learn to pay attention to multiple factors, regulate responses to provocation, and recognize emergent regularities.

5. Review, discussion and guidance on the use of metaphors in science

SCIENCE IS EXPLORATION, as a phrase (if not usually identified as metaphor), is reliably found in introductions to science and attempts to inspire students (e.g. Sagan, 1986; Fredericks, 2000). This is a version of the journey metaphor, but with only a hint of where one might be going. While EXPLORATION may animate novices, scientists will probably find metaphors of greater use if they more clearly suggest direction.

As presented here, the initial metaphor to explain the atom actually did have an objective, because it mapped from the solar system to atomic particles and directed scientists quite specifically to find electrons moving in orbits. The dataset metaphor in social science is less specifically focused yet suggests how the scientist can look for statistical relationships with which to piece together concepts and attempt to quantify causation. The social field metaphor radically widens the context, diffuses the social scientist's attention, frustrating prediction but promoting attention to qualitative dimensions. By accepting an adaptive dynamical system as metaphor the social scientist puts prediction aside in order to glimpse the operation of multiple cognitive and social feedback loops, near chaotic interaction, and periodic attraction into self-organized states.

By reviewing use of these central metaphors one sees how social science has attempted to mimic the apparent precision of physical science and track the most macro level tendencies in large social groups. But to account at the micro level for individual cases or to deal with unstable social situations, scientists are better advised to look for the non-linear, multi-causal complexity underlying social reality. Of course it was physical scientists who set this course, first having great success predicting motion of large objects using Newtonian formulations, then discovering dynamical systems to explain the fine details and to understand physics at the nuclear level.

The métier or vocation of each scientific metaphor discussed here makes clear that none of these central metaphors operates in a simple manner. Different sub-mappings apply in exploring different questions, all of the metaphors are subject to change as they are used, and they combine to compensate for their deficiencies.

5.1 Reviewing the target domain

Compared to the physical sciences, the social sciences may appear less strict, neither mathematically disciplined, nor genuinely scientific. The topic or target domain chosen here – highly contentious social encounters – is in fact a very rigorously studied subject in social science. The various theories brought to bear spring from many of the same conceptual insights as, for example, theories in astronomy, physics, and evolutionary biology.

To sharpen the discussion I chose social encounters characterized as fraught and volatile, and often used the example of police officers interacting with crime suspects at the time of, or very soon after, an alleged crime. Such encounters are fraught because so many factors and circumstances are in play, and volatile because of the potential for violence and harm. If science generally seeks to discover regularities, this topic is doubly challenging because violent outcomes, while of critical importance, are relatively infrequent and, as they arise from a wide range of triggering events, often defy comprehension. In this social science example the metaphors that might be most helpful are unlikely to be simple and prosaic, but more likely those with complex source domains.

The general outline of metaphor métier or vocation, used in the earlier sections, provides a framework for review by drawing our attention to each metaphor's initial form and the sub-mappings crucial in shaping hypotheses, modifications made, and the degree to which the metaphor is found useful and retained over the years.

5.2 Review of three metaphors in social science, their application, mappings and modifications

Reviewing the dataset approach in social science might be shown historically to have evolved from numeracy in the earliest days of trade and commerce – keeping track of possessions and currency, records of inventory and accounts arranged and manipulated very much as social science data is today; a simple and straightforward general-purpose scheme through which early civilizations managed and controlled a crucial and highly complex aspect of their lives, just as today social scientists use it to manage highly complex subject matter. One may presume a dataset to be theory-neutral because it is simply a collection of objects coded as numbers, whatever subject or topic it is applied to. But, by identifying metaphors inherent in the approach, built-in foregrounding and backgrounding of factors can be detected; for example, very simple notions of cause and effect are promoted while dynamic unfolding of rare events is backgrounded.

The dataset approach was presented here in terms of its key sub-mappings – SOCIAL PROCESS IS COLLECTION, MANIPULATION AND INSPECTION OF OBJECTS; PRECISION/ACCURACY IS ASSIGNING NUMBERS TO OBJECTS AND MANIPULATING THE NUMBERS; CHANGE IS ONE ENTITY PUSHING ANOTHER SO AS TO MOVE IT; CHOICES IN SOCIAL ENCOUNTER ARE COST VS. BENEFIT EVALUATIONS. The highly conventional CHANGE IS MOVEMENT mapping, very clearly operating in theorists' language, encourages what I try to show, in the social science context, as naive determinism.

In the very recent study of race in police-suspect violence discussed above, early dataset analysis showed, contrary to widespread belief, little effect and was inconclusive. The dataset metaphor, as it affected this study, wasn't revamped or replaced, but was expanded. The helper metaphors CONTROL and SEPARATION were added; these may have hurt more than helped, as some scientists and most learners struggle with the idea of separating out variance due to extraneous variables in order to control the statistical analysis. The results regarding race as linked to police shootings were again mostly inconclusive. This unexpected result was interpreted in terms of a rational choice metaphor.

This is not an indictment of the dataset approach or its underlying metaphors, but it does illustrate limitations of the dataset approach to explain complex social phenomena. When extensive dataset analyses are complete, both scientists and learners may know more about tabulation and statistical techniques, but still wonder about the subject matter – how the encounters of police and some suspects actually result in shootings while others do not. Anecdotes of individual cases seem to vary widely, though their data points may be identical.

The dataset approach is, of course, deliberately introduced, but the underlying SOCIAL PROCESS IS DATASET metaphor has become highly conventional and would not often be consciously recognized; it is closed as a cognitive aid for helping social scientists reason about their subject matter, while retaining metaphoric sub-mappings. The metaphor with its sub-mappings is clearly constitutive of the statistical theories used in social science and makes lexical contributions, such as the very specific statistical meanings of "probability," "holding factors constant" plus other statistics terms. But, unless used in conjunction with a strong subject matter theory, it is no more constitutive in explaining the social dynamics under study than, say, one's grocery list is to the intricacies of preparing and eating the Sunday meal.[10]

Reviewing the social field theory approach

Inspired by field theories in physics, social field theory contrasts sharply with the dataset approach. In general, social field theory is successful in communicating the field of forces notion – its hallmark – and this is a major contribution. As metaphor it stimulates curiosity and enables generations of social scientists to take a broader view by mapping the source domain of an observable physical force field to the difficult to observe non-physical dynamics of social process; By invoking the multitude of physical entities pushing and pulling on a physical plane or a matrix of forces operating in a hydraulic apparatus, the conceptual metaphor, SOCIAL PROCESS IS FIELD OF FORCES, guides thinking and promises detailed comprehension of what is happening using a new and insightful lexicon. But it offers few if any actual predictions. The social field theory metaphor is intuitively appealing and persuasive at least partly because it seems to accord with personal experience in the world.

The sub-mapping of SEMI-AUTONOMOUS FIELDS conjures up multiple levels of these fields of forces, with the layers sometimes reinforcing, sometimes inhibiting, each other. Additional sub-mappings – POSITION, DIRECTION, POWER – draw scientist's attention to regularities in complex dynamics while suppressing simplistic determinism. It is generative by prompting investigators, students and the lay public to see a bigger picture and consider multiple standpoints.

10. Consider whether a source domain of DATASET might better be thought of as a virtual interface (Preece et al., 1994. pp. 141–154) to the social process under study (target); the user (either scientist or learner) knows little of the actual workings of the social process, remains unaware of its structure and function, and the successful virtual interface doesn't help the user develop such understanding; instead the user becomes highly familiar with the structure and function of the virtual interface.

Terms from physical theories, such as “position,” “relation,” “directionality,” “control,” “power” and, of course, “field” have been re-deployed and continue to be part of the social science lexicon. But social field theory hasn’t been formalized enough to gain wide acceptance among social scientists. It is not unusual to find investigators using field notions and much of the vocabulary of the social field metaphor, but employing datasets to structure their research.

Reviewing the adaptive dynamical systems approach

Dynamical systems theory, imported from “hard” sciences such as astronomy and physics, conceives of physical movement on an extensive physical plane, and maps it to the psychosocial realm. It coexists with, and profits from, both the dataset and social field metaphors which continue to live on in the study of adaptive dynamical systems. The enriched framework prompts investigators to see social processes with fresh awareness and to look for patterns not contemplated by other approaches.

Where field theory sought regularities from the pushing and pulling in vast fields of forces, dynamical systems theory attempts to account also for the irregularities, including chaotic, cyclic, and sudden transmutations. The central metaphor, SOCIAL PROCESS IS FIELD OF FORCES includes the sub-mapping HIERARCHICALLY ARRANGED LEVELS AND TIME, so investigators are primed to observe changes at both micro and macro levels over an expanse of time. Micro psychodynamical patterns, often neglected in traditional social science, have clear but quite complex influence on macro outcomes and can help explain unexpected or disproportionate behavior.

The central metaphor also has the sub-mappings LINEAR AND NON-LINEAR MOVEMENT, and EQUILIBRIUM. The notions of linear and non-linear movement suggest that the social field can be both flat and curving terrain, and include some areas where movement is rapid and others where it is slow, regular, or showing no change at all. The concept of *emergence* is important, and while it echoes certain metaphoric notions, there is no clear source domain; it has only its technical definition as irreducible change.

Even when the adaptive dynamical systems approach is used, investigators sometimes employ datasets in experimental or observational studies. The difference is that, when such cases are combined with other findings, they fit together with, and are best interpreted using, the systems approach. The theory of dynamical systems and its supporting metaphors encompass an entire social encounter, not a snapshot, prompting investigators to observe the system jointly formed by parties in conflict. This guidance counteracts dataset assumptions and helps avoid its pitfalls. An example discussed above is the dataset study of “need for closure” interpreted in dynamical terms: as an indicator of micro level cognitive structure, "need for closure" inhibits more adaptable self-organization at the macro level.

What I show here to be conceptual metaphors (as best this can be substantiated in language use) are key concepts in the theory, making the metaphors theory-constitutive. They import terms (such as "non-linear movement" and "equilibrium") into the vocabulary of social scientists, building upon notions introduced by social field theory.

It is difficult to track changes in the metaphoric structure of dynamical systems theory when the theory is applied and tested through experiment and observation. Probably this is because the theory asserts the nature and qualities of change, putting scientists on the lookout, but making actual predictions difficult. When conditions are markedly altered, the theory warns of chaos and phase changes, but so far in social science it does not calculate where or when.

So the theory at present can be said to characterize situations and predict qualitative trends. With these qualifications, observational and experimental studies of various conflictual social encounters largely support dynamical system theory and its metaphoric mappings. SOCIAL ENCOUNTER IS A BALL ROLLING ON ATTRACTOR LANDSCAPE is a deliberate "helper" metaphor that communicates the dynamical systems subject matter efficiently and coherently (despite causing epistemological trouble if one attempts to interpret all of the analogical correspondences).

Thus guided, social science has made progress, as reviewed here, in understanding micro level cognitive and emotional states and investigators continue to be prompted to explore in greater detail, for example, patterns of feedback loops and non-linear change at the macro level. Developments in computer simulations of the ATTRACTORS metaphor stimulate theory development. Simulations also help training of practitioners, such as police officers who must deal with fraught and volatile encounters while suppressing fight/flight responses, observing trends among diverse factors, and calibrating their interventions; simulations ground submappings such as NON-LINEAR CHANGE and EQUILIBRIUM in actual experience. A great variety of unanswered questions continue to be posed, attesting to the generative effect of these metaphors and motivating their retention or continued use.

5.3 If one were to brief scientists, science popularizers, or science teachers about the use of metaphors, what might one say based on this chapter?

For scientists:

Look for metaphors you may not have noticed, and consider what they are saying about your subject. They may be part of the theory you are working with, your methodology, or may simply be implied by the language you use.

Are you using metaphoric language unrelated to your subject, perhaps confusing your audience or even contradicting yourself?

How narrowly focused are your metaphors, and is it the balance you want between micro and macro? Metaphors tend to favor macro events, perhaps omitting micro levels that will be important for more complete explanation or theorizing, even if causation cannot yet be demonstrated.

If you are developing datasets, or arguing from datasets, is there also a strong subject matter theory that guides your presentation of dataset results? Or, are you letting the statistics tell the whole story?

For journalists or those describing a scientific topic to the public:

Will you be using technical terminology and, if so, where does it come from and is it metaphoric?

Is there an existing narrative you will adopt and continue in use, or are you trying to present a new or different story line? Beware that you do not fall unintentionally into line with conventional wisdom, "established" facts, or some interest group's promotional strategy that is neatly imbedded in metaphor.

Have you tried out your choice of metaphoric language and asked friends or collaborators how it seems to affect their perspective?

Do you describe scientific findings as the results of data, the results of how things are theorized to work, or both?

For teachers of science:

Are you helping students identify metaphors in scientific materials, and showing them what the metaphors say as distinct from what observations alone might say?

Are students shown how metaphors might be taken literally, leading to epistemological confusion?

Do you use "helper" metaphors and, if so, teach also how each such metaphor is inaccurate? What are the unanswered questions that remain, either because it is disconfirmed or because the metaphor doesn't cover some observations at all?

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CHAPTER 8

THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM

Following a metaphor's path from its birth to teaching philosophy decades later

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This chapter analyzes three stops along the life path of the influential metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM. At the first two stops, the philosophers Searle, Hofstadter and Dennett argue about the literal truth of this metaphor in two academic papers. They embed the metaphor in complex metaphorical analogies, i.e., *deliberate metaphors*, for primarily persuasive purposes. The last stop analyzed is an academic lecture in philosophy which aims at explaining the metaphorical reasoning of the philosophers. The analysis focuses on the professor's modifications of one of Searle's deliberate metaphors. These modifications result in a misrepresentation of Searle's view on the mind. Linguistic evidence indicates that this misrepresentation influences the students' concept of the mind.

Keywords: recontextualization of metaphors, deliberate metaphors, metaphor across genres, deliberate metaphor use in academic articles, deliberate metaphor use in academic lectures

1. Introduction

Between 1955 and 1956 the scientists Allen Newell, Herbert A. Simon and Cliff Shaw developed a program to mimic human problem-solving skills, which is deemed to be the first Artificial Intelligence program (Crevier, 1993, p. 44) and thus laid the foundation to view computers as being able to think. A few years later, Hilary Putnam (1980, originally published in 1961) proposed the influential "computational theory of mind" (CTM), which he further developed with Jerry Fodor during the following decades. In CTM, thinking is considered to be a

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form of computing and the mind/brain is thought of as an information processor (Putnam, 1980; Fodor, 1975). This view on the mind and the brain evolved into a quite contentious position in modern Philosophy of Mind and rendered the theory-constitutive metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM.[1] The once theory-constitutive metaphor traveled from the academic arena into everyday life.[2] This is attested by a multitude of metaphorical expressions realizing this conceptual metaphor in ordinary English.[3] To name but a few examples, we talk about *encoding* and *decoding* meaning or about *storing* and *retrieving information*; sometimes, our brain does not *function* properly, which might result in problems of *online processing*. In fact, the metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM is still a widely spread (lay) view on how our brains work – so much so that the psychologist Robert Epstein (2016) has recently written an online article titled "The empty brain: Your brain does not process information, retrieve knowledge or store memories. In short: Your brain is not a computer".

Apart from its career from a novel theory-constitutive metaphor in science to a conventional metaphor in everyday life, THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM has also caused years of debates among scientists and philosophers about its "truth". The discussions that this metaphor provoked have often been theoretical (as opposed to empirical) and argumentative, but they have still furthered new scientific insights, particularly in the fields of Artificial Intelligence and Philosophy of Mind.

In the present chapter, I will analyze two argumentative academic papers that are responses to the metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM. I will use this analysis to illustrate that the metaphors used in a philosophy lecture from the 21st century are strongly influenced by the metaphors found in the two articles. Thus, in this chapter, I will consider the influence of the metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM over the course of 30 years, both on philosophical argument in two academic papers and on knowledge communication in an academic lecture.

The chronologically first point is represented by the academic article "Minds, brains, and programs", written by the philosopher John R. Searle and originally

1. I am adhering to the usual convention in Cognitive Linguistics, that is, writing what Lakoff and Johnson (1980) call *conceptual metaphors* in small capitals.

2. According to Boyd, theory-constitutive metaphors are "an irreplaceable part of the linguistic machinery of a scientific theory" (Boyd, 1993, p. 486; quoted in Knudsen, 2003, p. 1249).

3. See Lakoff and Johnson (1980) for metaphorical expressions as realizations of underlying conceptual metaphors.

published in 1980.[4] In Searle's article, the metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM (henceforth: *computer metaphor*) plays a crucial role, since Searle's goal is to refute the (metaphorical) comparisons established by this metaphor. For his rebuttal of the literal truth of the *computer metaphor*, Searle creates an impressively complex and elaborate metaphorical analogy known as the Chinese Room Thought Experiment. In a nutshell, the Chinese Room Thought Experiment metaphorically compares the claim that computers were capable of cognition, just because they are capable of producing human-like answers to a story, to the invented claim that Searle 'understands' Chinese, just because he produces Chinese symbols – on the basis of a set of rules in English. The reader is invited to conclude that Searle cannot be said to actually understand Chinese and transfer that to the computer program's alleged understanding of stories. Later in his article, Searle extends this initial analogy – or even substitutes it – by another metaphorical analogy which involves replacing the cognitive agent (Searle in the Chinese Room Thought Experiment) with non-cognitive sub-systems (here: a stomach).

The second point of interest in the life of the metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM is a response to Searle's article. The response is in fact another rebuttal. In their academic essay, which is simply called "Reflections", Douglas R. Hofstadter and Daniel C. Dennett refute Searle's view on the mind and thereby support perspectives of Artificial Intelligence, at least to some extent. Their argument also relates back to the metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM. This (further) demonstrates the importance of this metaphor in academic reasoning. The *computer metaphor* is at the heart of the scholars' arguments in the dispute between competing theories of Philosophy of Mind and/or Artificial Intelligence. Additionally, Hofstadter and Dennett's language use in their "Reflections" is not only also highly metaphorical, but "reuses" (some of) Searle's metaphors by modifying them for the essay's argumentative purposes. The latter aspect is not astonishing. As Searle's central concepts are communicated by making heavy use of complex metaphors, it is almost impossible not to refer to, or in some way "reuse", his metaphors when arguing against his view on the mind.

Similarly, when trying to explain Searle's concept of the mind in an educational setting, one can hardly succeed without referring to, or "reusing", his metaphors either. This is precisely what happens in the philosophy lecture I filmed at a US-American college about 30 years after the above described philosophical dispute.

4. Note that I will use the second edition of Hofstadter and Dennett's (2000a; 2000b) collection *The Mind's I* as a reference, since Searle's article was reprinted in their book and the philosophy course used this book for class.

In 2010, a professor gave a class in Philosophy of Mind for which the students had to read both Searle's article "Minds, brains, and programs" and Hofstadter and Dennett's reflections on it. In the discussion in class, the professor also refers to, and even quotes, Searle's metaphorical analogies in order to explain to his students what Searle's view on the mind is. Again, the *computer metaphor* underlies the reasoning of the discourse event. However, in this educational type of discourse, the general goal is not (primarily) persuading others of a particular view on the mind, but to communicate different concepts of the mind in the field of philosophy. The third part of my analysis below will show in how far this change in discourse goal is reflected in the "reuse" of metaphors in the philosophy lecture. I focus on the professor's "reuse" of Searle's metaphors and examine whether this reuse in the philosophy lecture enhances understanding.

Before I present my analysis of these three points in the life of the metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM, I will delineate and explain some of the linguistic concepts that the present analysis is based on. I will start with the most obvious notion of metaphor. In particular, three different dimensions of metaphor will be outlined: the linguistic, the conceptual, and the communicative dimension (see Steen, 2008, for a three-dimensional model of metaphor). The communicative dimension of metaphor is particularly important for the present study, as all the metaphors presented here are used deliberately. This is rather exceptional, since deliberate metaphors are only rarely found in language use (compared to non-deliberate ones) (cf. Steen, 2008, 2010).

The other concept that needs to be explained concerns the "reuse" of metaphors, especially across discourse events. The metaphors in Hofstadter and Dennett's reflections and in the philosophy lecture are not mere repetitions of Searle's metaphors. Instead, they constitute modified versions of Searle's metaphors. The modifications vary between the academic paper and the academic lecture, since they are adapted to the respective discourse goals and participants. In Linell's (1998a, 1998b) words, we can thus speak of a "recontextualization" of metaphors. I will briefly outline Linell's concept of recontextualization. Once the methodological framework is outlined, the analysis of metaphors centering on the *computer metaphor* will demonstrate the influence of this metaphor on the three different discourse events, particularly on the reasoning of the discourse participants. At the end of this chapter, I will summarize the findings and draw some conclusions about the development of metaphors and their functions at distinct points in time and across different genres. I will particularly highlight the value, but also the challenges of (complex) deliberate metaphors that originate in argumentative scientific settings and are recontextualized in educational settings.

2. Methodological and theoretical aspects

2.1 Steps of the analysis

The study presented here is based on a corpus composed of three discourse events. Two of those are written academic texts aimed at a readership of fellow academics (mainly philosophers). These academic papers do not present findings of research studies, but constitute strongly argumentative opinion pieces. The fact that the argumentation in these two papers is mainly based on metaphorical analogies attests the necessity of a metaphor analysis for determining the philosophers' line of reasoning. The third discourse event is also in the domain of philosophy, but very different from the first two texts. It is an academic lecture and thus represents spoken discourse. Furthermore, unlike the academic papers, the lecture is not a discourse event among equals, but is characterized by a knowledge differential. For this reason, the main aim of the academic lecture is to communicate knowledge rather than to persuade the participants of an opinion.

Since the present study is part of my PhD project that investigates the role of metaphor in knowledge communication in academic lectures, the starting point is the chronologically last discourse event, the philosophy lecture. The lecture was first completely transcribed and then all metaphors in the lecture were identified, using MIPVU (Steen, Dorst, Herrmann, Krennmayr, & Pasma, 2010). For the present purposes, the entirety of linguistic metaphors was searched for those that are repetitions or modifications of Searle's or Hofstadter and Dennett's original metaphors. These were further analyzed.

In a next step, the original computer-related metaphors by Searle, and by Hofstadter and Dennett, were examined in terms of features of what Steen (2008, 2010) labels *deliberate metaphors*. It was determined that all computer-related metaphors are in fact deliberate metaphors, whereupon I analyzed their specific functions in the argumentative texts. In a last step, the recontextualizations of metaphors were investigated. That is, metaphor "reuses" by Hofstadter and Dennett, and especially by the professor, were examined by looking at the way in which they are "reused" on a linguistic level. For instance, I determined whether or not the linguistic metaphors are mere repetitions of Searle's verbal *computer metaphor* or if the linguistic metaphors were modified: Are parts of the metaphors left out, substituted or elaborated? Each recontextualization of metaphors was then considered in its particular discourse context to establish the communicative purpose of the modification (or the lack thereof).

As this brief overview of my corpus and method has shown, *deliberate metaphor* and *recontextualization* are two key concepts for my analysis of the influence of THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM on the three discourse events in my corpus. Thus, the following sub-sections briefly outline these two theoretical aspects. In order to explain what deliberate metaphor is, I will introduce Steen's (2008, 2010) three-dimensional model of metaphor in language, thought, and communication. This is followed by a descriptuion of Linell's (1998a, 1998b) concept of recontextualization.

2.2 Metaphor in language, thought, and communication

In a recent attempt to extend the hitherto prevalent two-dimensional model of metaphor as a phenomenon of both language and thought (cf. Lakoff and Johnson, 1980), Steen (2008, 2010) proposes a model of metaphor that explicitly includes the dimension of communication. In each of the three dimensions, Steen differentiates between two oppositional characteristics of a metaphor. In the linguistic dimension, a metaphor can either be expressed indirectly, which is the default form of metaphor in Conceptual Metaphor Theory (Lakoff & Johnson, 1980), or directly (e.g., in the form of a simile or a longer comparison). In the dimension of thought, a metaphor is considered to be either a conventional or a novel connection between two conceptual domains. The new part of Steen's model of metaphor is the dimension of communication, in which he differentiates between non-deliberate metaphor and deliberate metaphor. Non-deliberate metaphors are essentially those metaphors that scholars of Conceptual Metaphor Theory have mainly been interested in over the past 40 years. Non-deliberate metaphors are not recognized *as* metaphors by discourse participants. Steen hypothesizes that this probably also means that non-deliberate metaphors are not processed as metaphors by cross-domain mappings, since they do not require the addressee's attention to turn to the metaphor's source domain (cf. Steen, 2008, 2010). In contrast, *deliberate metaphor* is defined precisely by their characteristic of shifting the addressee's attention to its source domain so that the addressee considers the current topic from this alien perspective (cf. Steen, 2008, p. 222). Due to a deliberate metaphor's pragmatic effect of changing (at least momentarily – and not necessarily consciously) an addressee's perspective on a given topic, deliberate metaphors can be considered as particularly effective tools in both knowledge communication discourses (such as the philosophy lecture) and argumentative discourses (such as the academic articles/essays by Searle and by Hofstadter and Dennett).

The theoretical delineation of deliberate metaphor is still in its infancy, which makes it hard to identify it, that is, to clearly distinguish deliberate from non-deliberate metaphor with a purely linguistic analysis. Even though Krennmayr (2011, pp. 154–155) proposes a list of features to look for when trying to identify possible instances of deliberate metaphor, and Reijnierse (2017) even suggests a 'Deliberate Metaphor Identification Procedure', there seem to be a number of cases in which the status of deliberateness still remains unclear (see Beger, 2019). Among other things, the lack of a clear identification procedure for deliberate metaphor renders this type of metaphor subject of lively scholarly debate (see, e.g., Gibbs, 2015a, 2015b; Gibbs & Chen, 2017, and Steen, 2015, 2017 for the most recent discussion). However, since the metaphors in the three discourse events of the following analysis are all clear cases of deliberate metaphor, adopting this concept for the present purposes allows us to consider potential effects on the addressees that this mandatory attention to the metaphors' source domains has.[5]

2.3 Recontextualization of metaphors

The metaphors that I will analyze below are not conventional metaphorical expressions that we can find in any discourse event in ordinary English. Instead, many of these metaphors are novel creations for the particular purpose of the respective discourse event. Moreover, though, the metaphors used by Hofstadter and Dennett as well as those by the philosophy professor in the lecture are also closely connected to Searle's original metaphorical analogies in that they pick up Searle's original metaphors and modify them in some way. Since these "reuses" and modifications of Searle's metaphors happen in different discourse contexts with distinct discourse goals, the metaphors in Hofstadter and Dennett's reflections as well as those in the philosophy lecture constitute what Linell (1998a, 1998b) calls "recontextualizations". Linell defines recontextualization

> as the dynamic transfer-and-transformation of something from one discourse/text-in-context (the context being in reality a matrix or field of contexts) to another. Recontextualization involves the extrication of some part or aspect from a text or discourse, or from a genre of texts or discourses, and the *fitting of this part or aspect into another context*, i.e., another text or discourse (or discourse genre) and its use and environment. (Linell, 1998b, p. 145, emphasis mine)

5. The metaphors analyzed in this chapter are clear cases of deliberate metaphors because they are either novel metaphors or direct metaphor – often even both. Direct metaphors have to be deliberate, because they refer to the literal sense of the respective word (they are technically not linguistic metaphors, because they are used in their literal sense. However, in the wider frame of discourse, they are supposed to be metaphorically compared to some other discourse constituent) (cf. Steen, 2010, pp. 52–54). Novel metaphors are also by definition used deliberately, since they do not have any lexicalized metaphorical meaning and thus require attention to the source domain. While almost all novel metaphors are also deliberate metaphors, cases of non-deliberate metaphor use can, for instance, be caused by children or mental patients (cf. Steen, 2016, p. 122). Due to the nature of my data, there are no such instances of novel but non-deliberate metaphor in my corpus.

According to Linell (ibid.), there are various discourse aspects that can be recontextualized, but these aspects include linguistic expressions. Thus, linguistic metaphors are certainly one aspect that can be recontextualized. As the quote from Linell above shows, recontextualization, of metaphorical expressions, for instance, is more than just referring to, or reusing, these expressions. Recontextualization is more dynamic and, crucially, since it involves the travelling of discourse aspects across different discourse events, includes the adaption of the recontextualized aspect to the particularities of the new discourse event. Thus, the term *recontextualization* is more apt for the present study than the term *reuse*.

Semino and her colleagues have already used Linell's concept of recontextualization in metaphor analysis (cf. Deignan, Littlemore, & Semino, 2013; Semino, Deignan, & Littlemore, 2013). They show how metaphors are first used in their original context and then analyze the nature of the adaptations that discourse participants make when they take these metaphors from their original contexts and adapt them to fit to the needs of different discourse contexts (ibid.). In the present chapter, I will provide a similar analysis. However, I will also demonstrate the challenges which elaborate metaphorical analogies pose for a professor in a lecture when he is forced to recontextualize such complex metaphors relatively spontaneously. I will start my analysis with examples of Searle's striking metaphor use in his paper "Minds, brains, and programs" (Searle, 2000), as Hofstadter and Dennett's opinion piece and the academic lecture are based on this paper.

3. Analysis: How THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM is embedded and recontextualized in deliberate metaphors to argue about, and explain, views on the mind in two different academic genres

I will start by analyzing the two main metaphorical analogies in Searle's line of reasoning in "Minds, brains, and programs". I will continue my analysis of the influence of THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM by examining selected recontextualizations of Searle's major deliberate metaphors in Hofstadter and Dennett's reflections on Searle's article. The last part of the analysis section also considers recontextualizations of Searle's deliberate metaphors involving the *computer metaphor*, but in a different discourse type with a different discourse goal: an academic lecture aiming at explaining Searle's concept of the mind.

3.1 Searle's metaphorical refutation of the "strong AI claim"

As I have mentioned above, the metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM had been the basis for scholars to reason about the nature of the mind for a few decades before Searle published his paper "Minds, brains, and programs". However, the reason why this metaphor plays a central role in Searle's paper is that for a group of researchers in Artificial Intelligence, it had apparently lost its metaphoricity. According to Searle (2000, p. 353), the strong view of Artificial Intelligence (AI) does not consider this metaphor to be merely a metaphor generating theories of the mind anymore. Instead, THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM is regarded as a literal and true statement. As Searle points out at the beginning of his paper, the strong AI view claims that "the appropriately programmed computer really *is* a mind, in the sense that computers given the right programs can be literally said to *understand* and have other cognitive states" (Searle, 2000, p. 353). Thus THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM, which was originally considered to be a metaphor whose mappings can help explain what the mind is, is taken as a literal comparison by proponents of the strong AI view. Also, the comparison operates in both directions so that we cannot only think of a mind as a computer program, but that we can also consider a computer program to be capable of cognition.

In his paper, Searle argues that this comparison is not appropriate. According to Searle, computer programs are not capable of cognition, primarily because they are lacking the physical and chemical requirements of our brain (Searle, 2000, p. 367). A considerable part of Searle's argument is based on elaborate metaphorical analogies. In the following, I will analyze the two major metaphorical analogies in Searle's (2000) argumentation. These two central metaphorical analogies both involve the metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM or its short form A BRAIN'S MIND IS A COMPUTER PROGRAM. The first metaphorical analogy I will analyze centers on the well-known Chinese Room Thought Experiment. Afterwards, I will analyze the second key analogy, which I labeled the Stomach Example.

3.1.1 *Searle's first major metaphorical analogy: The Chinese Room Thought Experiment*

At the beginning of his paper, Searle (2000, p. 354) describes work by Schank and Abelson (1977), as proponents of the strong AI view allegedly use this work as support for the claim that computers (or their programs) are capable of human understanding. In particular, a computer program developed by Schank and Abelson (1977) which aims at simulating human story understanding is taken as evidence for the strong AI claim (cf. Searle, 2000, p. 354). Searle, however, does not agree with this reasoning and devotes the first part of his refutation of the strong AI claim to showing why Schank and Abelson's computer program cannot be considered as evidence for computer (programs) possessing actual cognition. According to Searle (ibid.), proponents of the strong AI claim equate Schank and Abelson's (1977) computer simulation of human story understanding with human cognition in general, because of the following sub-comparisons. In Schank and Abelson's simulation, the computer receives input, that is, a story, just like the brain of a human being would do. The input is then processed by a special program, which is compared to what the mind would do. Afterwards, the computer is asked questions about the story that go beyond what was explicitly stated in the story. Thus, in order to give human-like answers to these questions, the computer (program) has to engage in inferencing, which is usually a feature reserved for human cognition. And indeed, Schank and Abelson's computer program produces output that is indistinguishable from human-generated answers. Proponents of the strong AI claim take this to mean that understanding takes place. They then generalize that cognition can essentially be defined as 'receiving input – having the appropriate program process it – producing (human-like) output'. Note that all of these comparisons are based on the metaphor A BRAIN'S MIND IS A COMPUTER PROGRAM.

In order to prove the proponents of the strong AI view wrong in regard to their claim that Schank and Abelson's computer program is capable of human cognition, Searle creates a complex and elaborate source domain scenario which is supposed to be mapped onto the entire reasoning described above. This means that the target domain of Searle's newly invented metaphor is in fact the original metaphor A BRAIN'S MIND IS A COMPUTER PROGRAM. As the target domain of Searle's metaphorical analogy is in fact a metaphor itself, it consists of two parts: the operation of computer programs such as Schank and Abelson's (1977) and the operation of minds. Thus, this bipartite target domain comprises a source domain, OPERATION OF COMPUTER (PROGRAMS), and a target domain, OPERATION OF A BRAIN'S MIND. These two parts of the general target domain are supposed to be compared to one another. However, unlike the proponents of the strong AI claim, Searle's goal of this (metaphorical) comparison is to demonstrate that this comparison is unacceptable. These complexities of the target domain of Searle's first metaphorical refutation of the strong AI claim are illustrated in Figure 1.

The bipartite target domain with the embedded metaphor A BRAIN'S MIND IS A COMPUTER PROGRAM suggests that Searle has to provide an equally complex source domain from which to consider the various aspects of the target domain as well as the comparison within the target domain. Indeed, Searle provides a quite detailed description of a newly created source domain, which consists of two parts (Searle,

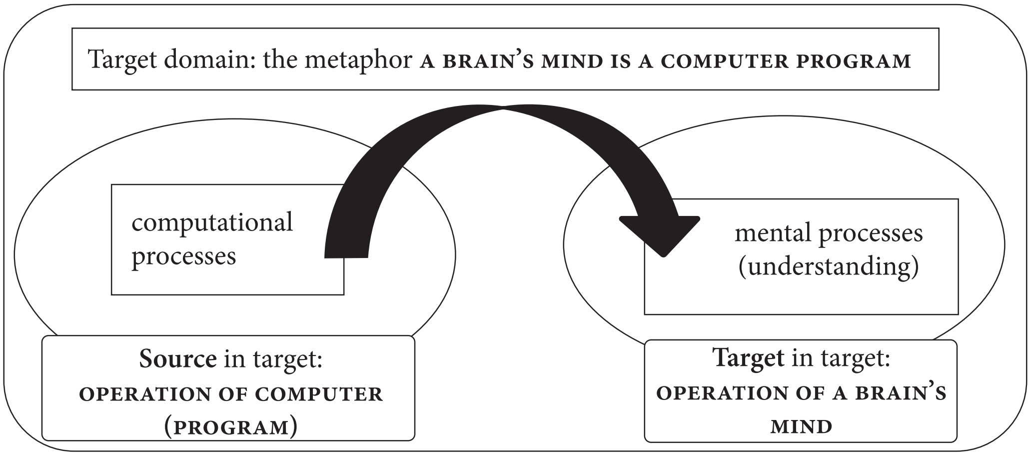

Figure 1. Complex bipartite target domain of Searle's first metaphorical refutation of the strong AI view

2000, p. 355).[6] Both parts are relatively rich scenarios in which Searle, similar to the computer in Schank and Abelson's simulation of story understanding, receives written stories to which he responds in the form of answers to questions about these stories. Due to the Chinese symbols involved in the first scenario, this source domain is known as the Chinese Room Thought Experiment.

Searle starts his Chinese Room Thought Experiment with what I call the *Chinese Scenario*. This is also the most elaborate of the two source domain scenarios. Example (1) below is an excerpt of Searle's article which illustrates the most important aspects of the *Chinese Scenario* of the source domain CHINESE ROOM THOUGHT EXPERIMENT.

(1) Suppose that ***I'm locked in a room and given a large batch of Chinese writing***. Suppose furthermore (as is indeed the case) that ***I know no Chinese, either written or spoken […]. To me, Chinese writing is just so many meaningless squiggles*** . Now suppose further that ***after this first batch of Chinese writing I am given a second batch of Chinese script together with a set of rules for correlating the second batch with the first batch. The rules are in English and I understand these rules*** […]. Now suppose also that ***I am given a third batch of Chinese symbols together with some instructions, again in English, […] and these rules instruct me how to give back certain Chinese symbols***

6. Searle's newly constructed source domain also consists of scenarios that are invented, that is, that do not naturally exist in our environment. Wee (2005) calls such invented source domains 'constructed sources'. In his paper (ibid.), Wee shows that such constructed sources function as discourse strategies. The presently discussed source domain invented by Searle is one of the striking examples provided and analyzed in Wee's (2005) paper.

> ***with certain sorts of shapes in response to certain sorts of shapes given to me in the third batch*** . (Searle, 2000, p. 355; emphasis mine)[7]

As we can see in Example (1), Searle constructs a scenario that is in some ways similar to Schank and Abelson's (1977) computer program which aims at simulating human story understanding. Searle receives a large batch of Chinese writing, which is similar to feeding a computer with scripts. In both cases, the recipients are supplied with information about stereotypical structures of everyday situations, and this information is necessary to answer questions, for instance, questions about stories involving such prototypical situations. The second batch of Chinese symbols in Searle's source domain is supposed to be mapped onto the story that the computer was given in Schank and Abelson's simulations. Similarly, the third batch of the Chinese symbols Searle receives in Example (1) is to be mapped onto the questions Schank and Abelson's computer was provided with. Lastly, in order to be able to create answers in Chinese despite being unable to understand either the Chinese questions or the Chinese answers he produces, Searle receives English rules that allow him to correlate the different symbols he does not comprehend – in a way that native speakers of Chinese are tricked into thinking that the answers he produces are generated by an actual Chinese speaker. This last aspect of the source domain supposedly corresponds to the program that the computer in Schank and Abelson's simulations of story understanding uses. Interestingly, Searle (2000, p. 355) explicitly spells out these intended mappings from source (*Chinese Scenario*) to target domain (OPERATION OF COMPUTER (PROGRAM)) after he describes the *Chinese Scenario* illustrated in Example (1). Thus, the readers know exactly which aspects of the partial target domain OPERATION OF COMPUTER (PROGRAM) (see Figure 1) to understand in terms of what particular aspects of the source domain's *Chinese Scenario*.

This intended mapping from the *Chinese Scenario* to the target domain part OPERATION OF COMPUTER (PROGRAM) is illustrated in Figure 2. As Figure 2 also shows, the other part of the general source domain CHINESE ROOM THOUGHT EXPERIMENT is still missing. In his academic paper, Searle continues by filling this gap. He provides another scenario, which I call the *English Scenario*. This second part of the source domain is described in less detail, as it is something the prototypical reader of Searle's article is quite familiar with, as the excerpt in Example (2) demonstrates:

(2) Now just to complicate the story a little, <u>imagine that</u> ***these people*** [who gave Searle the batches of Chinese symbols, etc. in Example (1)] ***also give me stories in English, which I understand, and then they ask me questions in***

7. In the examples throughout this chapter, I highlight metaphorically used words in bold and italics. Underlined constructions signal the use of metaphors.

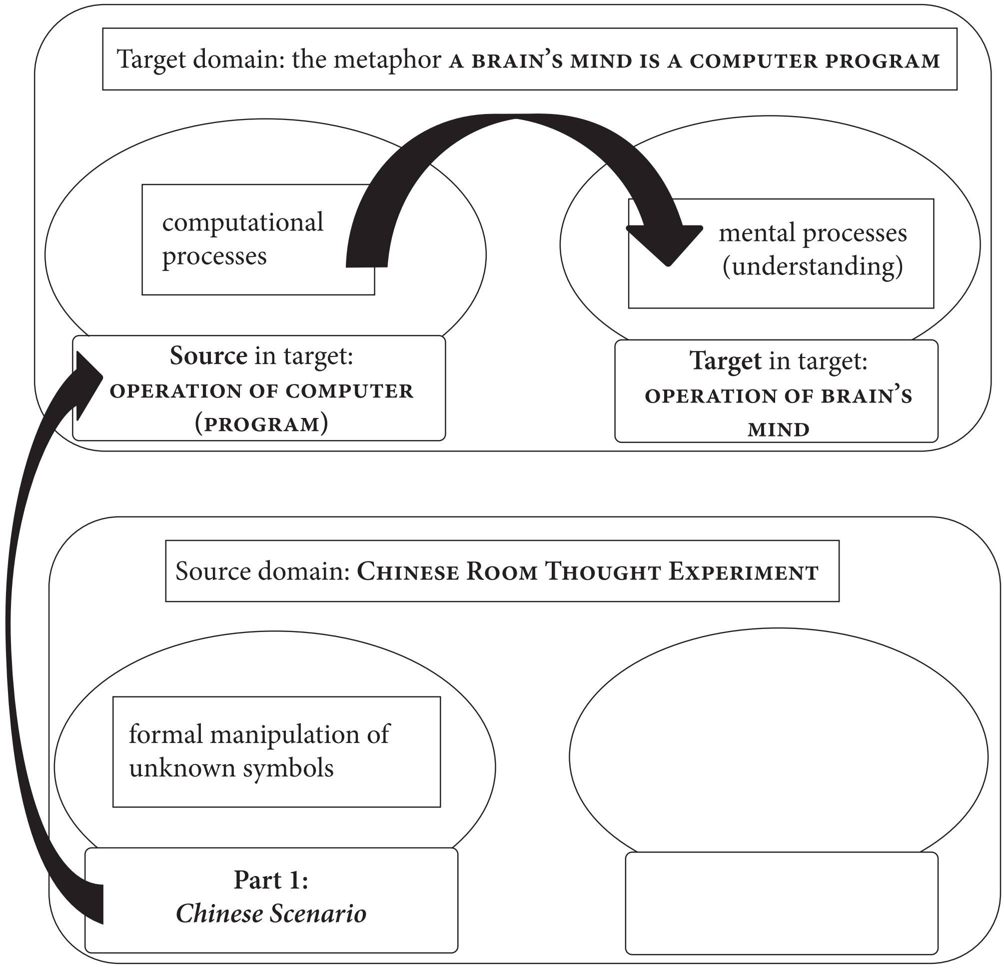

Figure 2. Partial source domain and target domain of Searle's first metaphorical refutation of the strong AI view.

> ***English about these stories, and I give them back answers in English*** .
>
> (Searle, 2000, p. 355)

Apart from the aspect of being locked in a room (see beginning of the source domain scenario in Example (1) above), the scenario that Searle describes in Example (2) is probably very familiar to most English speakers. Crucially, everyone who has ever heard or read a story in his mother tongue and answered questions about it afterward, will agree that the process that took place between listening to, or reading, the story and answering questions about it is in fact what we call *understanding*. Furthermore, this kind of understanding is usually considered an instance of human cognition in general. Thus, the *English Scenario* that Searle describes in Example (2) can be considered as an example of mental processes and therefore corresponds to the target domain part OPERATION OF BRAIN'S MIND in the general target domain A BRAIN'S MIND IS A COMPUTER PROGRAM (see Figure 2).

The correspondences between the *Chinese Scenario* of the source domain and OPERATION OF A COMPUTER (PROGRAM) of the target domain on the one hand, and the correspondences between the *English Scenario* in the source domain and OPERATION OF A BRAIN'S MIND in the target domain on the other hand, are quite important for Searle's refutation of the strong AI claim. However, the crucial aspect of his metaphorical analogy is that the reader comes to the conclusion that the *Chinese Scenario* and the *English Scenario* involve two quite distinct processes. Even though both scenarios look alike from outside the Chinese Room, the processes taking place *in* the room are vastly different. The *English Scenario* involves mental processes in form of story understanding whereas the *Chinese Scenario* is merely mechanical symbol manipulation according to a set of rules.

Since each of these two scenarios of the source domain CHINESE ROOM THOUGHT EXPERIMENT corresponds to one of the two parts of the target domain A BRAIN'S MIND IS A COMPUTER PROGRAM, the conclusion to be drawn from this complex metaphorical analogy is that just like the two scenarios in the source domain, the two elements of the target domain are quite distinct: Computational processes are as dissimilar to mental processes as the processes in the *Chinese Scenario* are dissimilar to those in the *English Scenario*. Therefore, a brain's mind is not at all a computer program and Schank and Abelson's computer simulation of human understanding cannot be seen as evidence for cognition in computers. The conclusion that the metaphor A BRAIN'S MIND IS A COMPUTER PROGRAM cannot be taken as literal truth is the intended outcome of Searle's invitation to follow his complex metaphorical reasoning of the Chinese Room Thought Experiment. I summarize the different metaphorical comparisons of Searle's Chinese Room Thought Experiment as the first metaphorical refutation of the strong AI claim in Figure 3.

After this first metaphorical refutation of the strong AI claim, Searle continues his article by providing people's reactions to the Chinese Room Thought Experiment. Interestingly, these people are researchers or workers within the field of Artificial Intelligence, most of whom disagree with Searle and reject his metaphorical analogy of the Chinese Room Thought Experiment. In his paper, Searle categorizes the AI researchers' responses and replies to each category, rebutting their arguments. One of these rebuttals is closely connected to the metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM. I will continue my analysis with this second metaphorical analogy, which is the foundation of this particular rebuttal.

3.1.2 *Searle's second major metaphorical analogy: The stomach example*

Searle's rebuttal of what he calls the "systems reply" is based on another metaphorical analogy, which is very similar to the one I have analyzed in the previous

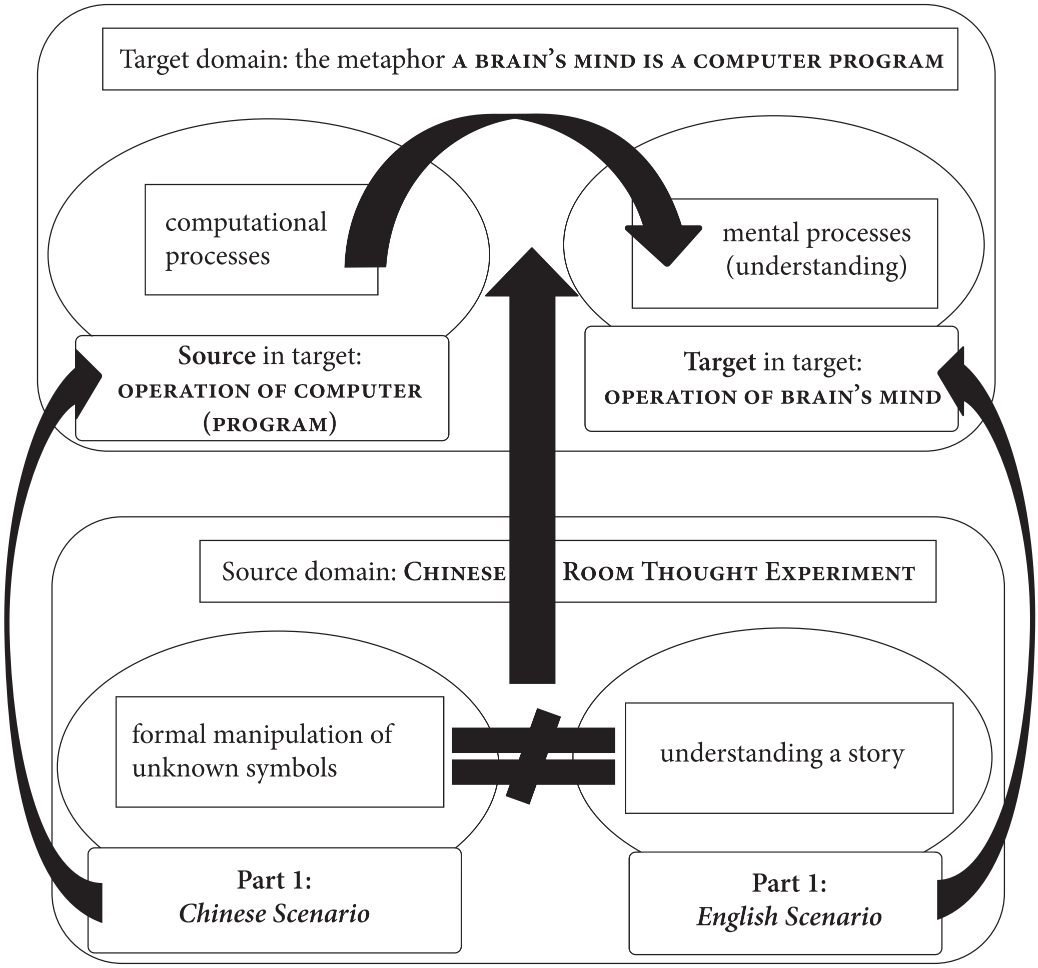

Figure 3. Complete source and target domain of Searle's first metaphorical refutation of the strong AI view.

sub-section. Due to space limitations, I will not recount the "systems reply", since it is very similar to the general strong AI view, so that Searle's metaphorical argument refuting the "systems reply" can even be understood without a summary of the reply. In Searle's metaphorical rebuttal of the "systems reply", the reader is once more faced with a bipartite source and target domain. Again the target domain constitutes the original metaphor A BRAIN'S MIND IS A COMPUTER PROGRAM Thus, the changes in this second metaphorical analogy concern its source domain.

Searle (2000, p. 360) points out that the "systems reply" equates cognition with having input, output and a program in between – which is essentially what the strong AI view believes, on the grounds of Schank and Abelson's (1977) simulations discussed above. In order to point out another (in his words "absurd") aspect of such an equation, Searle provides the reader with another source domain from which to consider the strong AI claim/the "systems reply". The difference to the CHINESE ROOM THOUGHT EXPERIMENT source domain is, essentially, that there is no human agency involved anymore. Searle's metaphorical argument is illustrated in Example (3):

(3) If we are to conclude that there must be cognition in me on the grounds that I have a certain sort of input and output and a program in between, then it looks like all sorts of noncognitive subsystems are going to turn out to be cognitive. For example, ***there is a level of description at which my stomach does information processing, and it instantiates any number of computer programs, but I take it we do not want to say that it has any understanding***. (Searle, 2000, p. 360)

In the excerpt in Example (3), Searle first reminds the reader of the topic of his argumentation, that is, that the metaphor A BRAIN'S MIND IS A COMPUTER PROGRAM (target domain) is not literally true. Both parts of the target domain are indicated in the first half of the first sentence in Example (3). The word *cognition* points at the target domain part OPERATION OF BRAIN'S MIND. Searle then designates the other target domain part OPERATION OF COMPUTER (PROGRAM) by mentioning the main constituents *input*, *output* and *a program*. The truth of the metaphorical comparison within the target domain is rejected in the second half of the sentence. Searle argues that taking the metaphor A BRAIN'S MIND IS A COMPUTER PROGRAM literally would mean that all kinds of non-cognitive subsystems featuring input, output and a program were able to engage in cognitive processes.

While this argumentation might still be somewhat abstract, Searle skillfully continues by providing an example of another possible non-cognitive subsystem, his stomach. *Stomach* functions as part of the source domain that Searle creates for the reader to think about the target domain A BRAIN'S MIND IS A COMPUTER PROGRAM. Using the stomach as part of the source domain is effective, since all readers are quite familiar with a stomach and they will in all probability agree with Searle's next point, which is that whatever a stomach does is far removed from understanding and cognition. This comparison between processes of a stomach and processes of a brain constitutes the source domain of Searle's second major metaphorical analogy for the refutation of the strong AI claim. Just as in Searle's first main metaphorical analogy analyzed above, the conclusion that the two processes (stomach processes versus brain processes) of the source domain have nothing in common is supposed to be mapped onto the comparison established in the target domain A BRAIN'S MIND IS A COMPUTER PROGRAM. Thus, Searle's second metaphorical attempt at refuting the strong AI claim has a structure very similar to the first one. Furthermore, three of the four components of the metaphorical analogy are almost identical. This second major metaphorical analogy is illustrated in Figure 4.

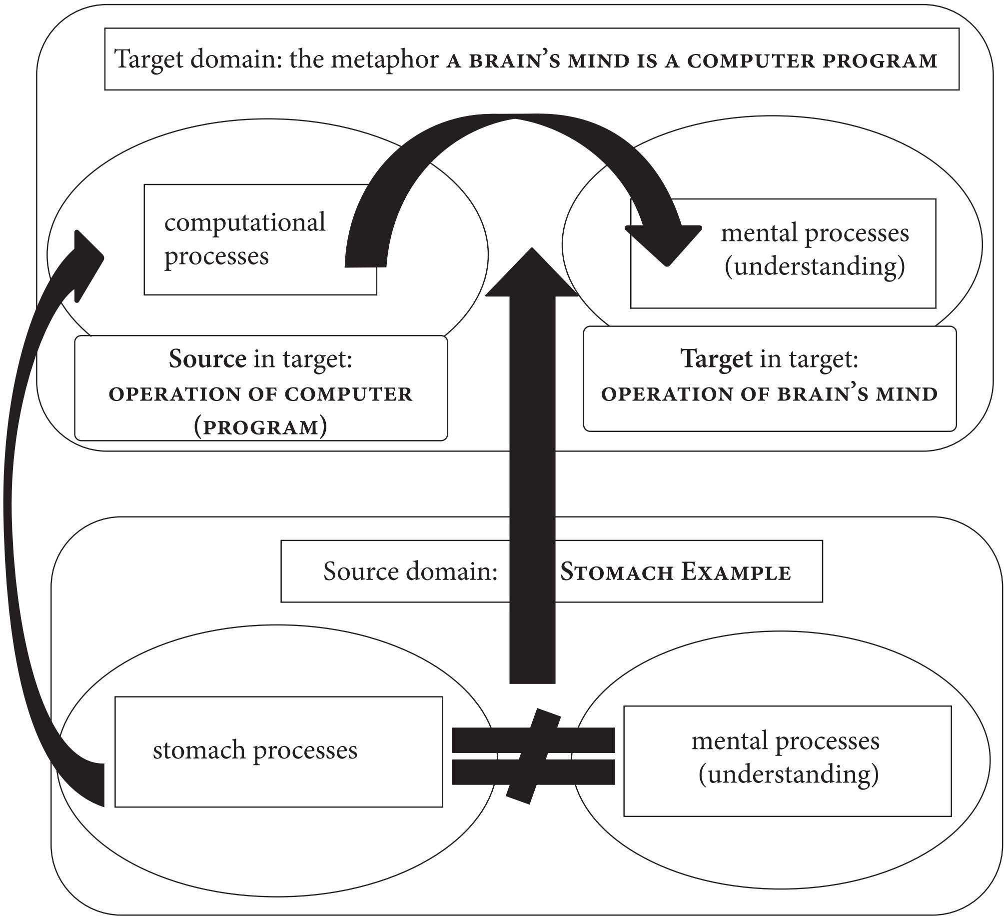

Figure 4. Searle's second metaphorical refutation of the strong AI view: The Stomach Example.

As we can see in Figure 4, the target domain in Searle's second metaphorical analogy refuting the strong AI claim is identical to his first metaphorical analogy (see Figure 3). The source domain in Figure 4 features mental processes, which is a more general version of the story understanding in the *English Scenario* of the CHINESE ROOM THOUGHT EXPERIMENT. At the same time, it is identical to part of the target domain, so that there is no mapping necessary between these source and target domain parts. The left-hand side of Figure 4 shows that the reader is to understand computational processes in term of stomach processes. Their shared aspects are, according to Searle in Example (3) above, the very features that the AI researchers with the "systems reply" apparently identified as necessary and sufficient to describe mental processes: receiving input, instantiating a program, and producing output (accordingly). As the straight arrow in Figure 4 indicates, the crucial aspect of Searle's analogy is that the discrepancy between the processes of the source domain is mapped onto the relation between the processes of the target domain. Thereby, Searle once more refutes the literal truth of the metaphor A BRAIN'S MIND IS A COMPUTER PROGRAM.

As I have demonstrated throughout this section, the two main metaphorical analogies that Searle (2000) uses in his paper "Minds, brains, and programs" to refute the strong AI claim are both inseparable from the original *computer metaphor*, as they both use its shortened version as their target domains. A year after Searle's initial publication of "Minds, brains, and programs", Hofstadter and Dennett (2000a) reject Searle's two metaphorical analogies by pointing out flaws in the alleged correspondences. They do so by employing even more metaphors in their argumentation, as the following section will point out. These metaphors are consequently also connected to the original metaphor A BRAIN'S MIND IS A COMPUTER PROGRAM.

3.2 Hofstadter and Dennett's rebuttal of Searle's metaphorical rejection of the strong AI claim

Unlike Searle, Hofstadter and Dennett have more faith in the possible truth of the metaphor A BRAIN'S MIND IS A COMPUTER PROGRAM. The conclusion of their reflections is that

> [m]inds exist in brains and may come to exist in programmed machines. If and when such machines come about, their causal powers will derive not from the substances they are made of, but from their design and the programs that run in them. (Hofstadter & Dennett, 2000a, p. 382)

As Hofstadter and Dennett seem to approve of the strong AI claim, the aim of their reflections is to point out flaws in Searle's (metaphorical) argument so that his refutation of the strong AI claim is nullified. Since much of Searle's reasoning is communicated via metaphor, Hofstadter and Dennett recontextualize Searle's main metaphors in their reflections.

At the outset of their reflections, Hofstadter and Dennett (2000a, p. 373) acknowledge that Searle's entire argumentation throughout his article hinges on the Chinese Room Thought Experiment. Accordingly, they spend the majority of their reflections on Searle's paper tearing apart the metaphorical analogy involving the Chinese Room Thought Experiment. In their recontextualizations of Searle's complex analogy, they take different aspects and elaborate them in order to show that the analogy is inadequate and can therefore not disprove the strong AI claim. It would go beyond the scope of this contribution to present all recontextualizations of Searle's Chinese Room Thought Experiment metaphor. I will therefore demonstrate the general principle of Hofstadter and Dennett's recontextualizations by providing one example. The excerpt in Example (4) below shows how

Hofstadter and Dennett reject the correspondence between the *Chinese Scenario* of the source domain and OPERATION OF A COMPUTER (PROGRAM) in the target domain of Searle's analogy.

(4) ***We find it hard enough to memorize a written paragraph; but Searle envisions the demon*** [i.e., Searle as the human agent in the *Chinese scenario*][8] ***as having absorbed what in all likelihood would amount to millions, if not billions, of pages densely covered with abstract symbols – and moreover having all of this information available, whenever needed, with no retrieval problems***. (Hofstadter & Dennett, 2000a, p. 375)

As Example (4) demonstrates, Hofstadter and Dennett do not simply reject Searle's *Chinese Scenario*, but they change it. Instead of simply rejecting the entire metaphorical analogy, they reject a correspondence and provide a more detailed version of the actions in the *Chinese Scenario* to support their argument. Remember that in Searle's metaphor version, Searle merely stated that he (called *demon* in Example (4)) received batches of Chinese symbols along with English rules that allow him to correlate these symbols and produce more Chinese symbols without understanding any Chinese. The reader was supposed to map this process onto the partial target domain, that is, OPERATION OF A COMPUTER (PROGRAM). As we can see in Example (4), though, Hofstadter and Dennett modify the *Chinese Scenario* by providing a much more detailed version of the actions of the human being (or demon) in this scenario. This recontextualization is supposed to give the reader a more realistic description of the actions of the human being in the *Chinese Scenario* that would correspond to what a computer (program) does when simulating story understanding.

The elaboration is more detailed in two aspects: (1) the necessary amount of pages of what Searle just called "a batch" of Chinese symbols and (2) the fact that correlating and producing symbols would in fact mean memorizing and retrieving an incredible amount of symbols. The point of this recontextualization by elaboration is to convince the reader that it is impossible for a human being to perform such tasks.[9] Additionally, in the very first sentence of Example (4), Hofstadter

8. Calling the human agent in Searle's Chinese scenario "Searle's demon "or "demon "is indicative for Hofstadter and Dennett's general tone in their reflections on Searle's paper. Their reflections are characterized by evaluative comparisons and labels, sarcasm, and the like.

9. Also note that while Searle's metaphorical *Chinese Scenario* conveyed the message that a computer simulating story understanding engages in something 'less intelligent' than actual human understanding of stories (mechanical matching of symbols), Hofstadter and Dennett's recontextualization of this partial source domain can be said to send the opposite message. Their more detailed account of the actions in the *Chinese Scenario* suggests that the computer is capable of carrying out tasks whose complexity is beyond a human being's ability to perform.

and Dennett skillfully set up the opposition between what normal human beings already find difficult to do (memorizing a written paragraph) and what Searle suggests a human is capable of. The reminder of the difficulties some people have memorizing a single paragraph adds to the persuasive power of the recontextualization of the *Chinese Scenario* metaphors. It probably makes the reader even more likely to draw the intended conclusion that the centerpiece of Searle's entire analogy of the Chinese Room Thought Experiment is flawed and can therefore not be considered as an argument against the strong AI claim. Thus, Hofstadter and Dennett's recontextualizations of Searle's metaphors, just as Searle's original metaphor use, also have a persuasive function in an argumentative text type.[10]

Apart from frequent recontextualizations of Searle's central metaphorical analogy involving the Chinese Room Thought Experiment, Hofstadter and Dennett (2000a) also recontextualize the second key analogy in Searle's (2000) article "Minds, brains, and programs", that is, the Stomach Example. As the excerpt in Example (5) below demonstrates, Hofstadter and Dennett recontextualize the Stomach Example not by elaborating on particular aspects, but by over-simplifying the metaphorical analogy and using part of it as a target domain which they embed in their own novel metaphorical analogy:

(5) If you can see all the complexity of thought processes in a churning stomach, then ***what's to prevent you from reading the pattern of bubbles in a carbonated beverage as coding for the Chopin piano concerto in E minor? And don't the holes in pieces of Swiss cheese code for the entire history of the United States? Sure they do – in Chinese as well as in English. After all, all things are written everywhere! Bach's Brandenburg concerto no. 2 is coded for the structure of Hamlet – and Hamlet was of course readable (if you'd only known the code) from the structure of the last piece of birthday cake you gobbled down*** . (Hofstadter & Dennett, 2000a, p. 381–382)

The first sentence in Example (5) is a rhetorical question in which Hofstadter and Dennett establish a metaphorical analogy. The analogy indicates that Searle's metaphorical comparison of thought processes and a churning stomach is comparable to reading the pattern of bubbles in a carbonated beverage as coding for a certain musical composition. The structure of Hofstadter and Dennett's analogy in Example (5) thus follows the pattern we saw in Searle's analogies of the Chinese Room Thought Experiment and Stomach Example. That is, Hofstadter and

10. For different functions of metaphors in scientific texts, including a persuasive function, see Semino (2008, p. 134), who incidentally also analyzes a text by Daniel Dennett (Semino, 2008, pp. 125–134). Also see Semino, Deignan and Littlemore (2013, pp. 45–46) for the interplay of an explanatory function and a persuasive function in a single metaphor.

Dennett compare two entities that have nothing in common (bubbles in a carbonated beverage and the Chopin piano concerto in E minor) and subsequently map the resulting incongruity onto a comparison in the target domain of the analogy (see Figure 5). Hofstadter and Dennett's analogy in Example (5) recontextualizes Searle's Stomach Example metaphors by turning the source domain comparison of Searle's analogy (see Figure 4) into the target domain of their own analogy. The function of their resulting analogy is also a persuasive one: Hofstadter and Dennett try to convince the reader that the two elements in the target domain do not share anything (important).

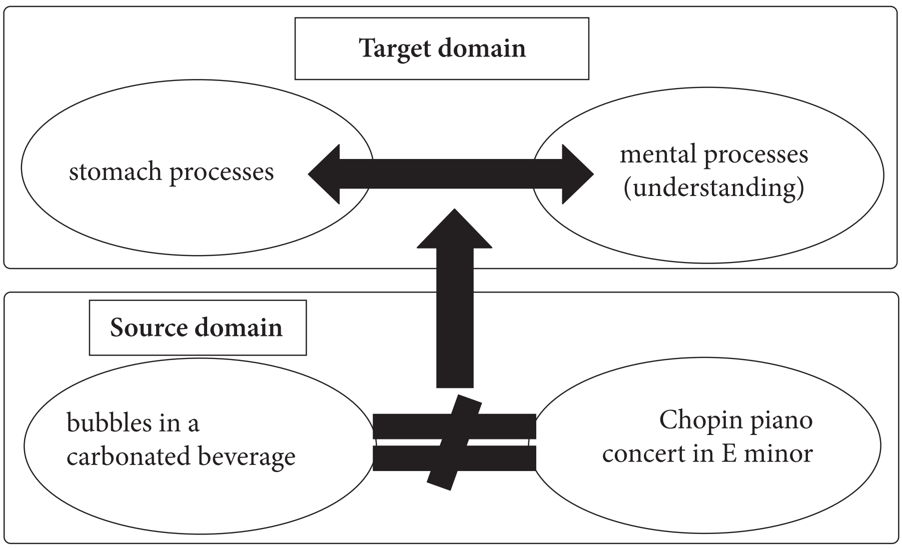

Figure 5. Hofstadter and Dennett's metaphorical rebuttal of Searle's stomach example.

As we saw earlier, Searle's argument involving the Stomach Example hinges on urging the reader to consider the strong AI claim from the perspective of the source domain comparison. By using Searle's source domain comparison as their own target domain, Hofstadter and Dennett's can point out flaws in the foundation of Searle's reasoning in the Stomach Example. Since Hofstadter and Dennett substantially weaken Searle's refutation of the strong AI claim with their analogy in Example (5), they indirectly support the strong AI claim and thus the possible truth of the metaphor A BRAIN'S MIND IS A COMPUTER PROGRAM. This is the exact opposite of what Searle tried to accomplish with deliberate metaphors of the Stomach Example.

The analysis of the first sentence of Example (5) and Figure 5 seem to reveal the structure and the function of Hofstadter and Dennett's partial rebuttal of Searle's Stomach Example. Yet, the logic of their argumentation in the analogy (or analogies) in Example (5) may not be entirely clear. Their analogy aims at ridiculing Searle's comparison between stomach processes and mental processes.

However, this is also precisely the point in Searle's Stomach Example. Otherwise, Searle could not have mapped the impossibility of comparing stomach processes and brain processes onto the metaphor A BRAIN'S MIND IS A COMPUTER PROGRAM in the target domain of the Stomach Example. Thus, even though Hofstadter and Dennett's recontextualization of Searle's Stomach Example analogy attempts to refute Searle's rebuttal of the strong AI claim, it remains unclear which step in Searle's metaphorical reasoning Hofstadter and Dennett criticize with their analogies in Example (5).

Also note that Hofstadter and Dennett's analogy in Example (5) can be considered a simplification of Searle's Stomach Example, as it only takes into account the analogy's source domain. They do not reuse Searle's entire analogy, but only embed part of it for their local rhetorical purposes. However, despite their own simplification, Hofstadter and Dennett are able to insinuate that it is Searle who oversimplifies matters. This is indicated by the use of hyperbole in Example (5). Hofstadter and Dennett use increasingly absurd comparisons, such as comparing holes in Swiss cheese to the history of the United States, for their analogy's source domain. This form of humor mixed with the deliberate metaphors results in ridiculing Searle's metaphorical argumentation. By providing progressively grotesque comparisons, culminating in the structure of Hamlet being readable from the structure of a piece of already eaten (!) birthday cake, Hofstadter and Dennett may even portray Searle as slightly insane.

In summary, the analysis of Hofstadter and Dennett's recontextualizations of Searle's most important deliberate metaphors demonstrated how metaphors can be taken out of their original context and, by carrying out some well-thought-out modifications, can be used for other purposes in a different discourse event. In this case, Hofstadter and Dennett's recontextualizations of Searle's metaphors have the desired effect of dismantling Searle's argumentation in his refutation of the strong AI claim, and perhaps of discrediting Searle in general.

All of the deliberate metaphors analyzed this far center on the metaphor that constitutes our starting point, THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM, as all of them are used to argue for or against the literal truth of this metaphor. Furthermore, we saw that the deliberate metaphors in both academic papers are of paramount importance in the philosophers' argumentation. The reader is also forced to consider the topics of the argumentation from the view of the metaphors' source domains, since these are newly constructed, quite elaborate, and in some instances even sprinkled with other rhetorical devices such as hyperbole. Thus, the deliberate metaphors presented so far are in all probability used by the readers in order to make sense of the arguments presented. The highly persuasive function of all deliberate metaphors analyzed here may therefore have quite some effect on readers' views on the mind.

Another feature that all deliberate metaphors in the academic articles by the three philosophers share is that they are carefully planned. The next point in the life of the metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM that I want to consider here will take us to a more spontaneous discourse event. It takes place approximately 30 years after the publication of the philosophical argument between Searle and Hofstadter and Dennett. In 2010, a lecture in Philosophy of Mind at a US-American college centers on 'the same old question', that is, whether or not computer programs are capable of human understanding. Thus, the literal truth of the metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM is once more contemplated.

Additionally, the students of this course have read the two texts analyzed hitherto (Hofstadter & Dennett, 2000a; Searle, 2000) and the professor as well as the students directly address the texts over the lecture, sometimes even by reading out passages. Since the argumentation in both academic texts is highly metaphorical, the main metaphors analyzed above are recontextualized in the philosophy lecture. In the following sub-section, my analysis focusses on three recontextualizations of Searle's Stomach Example, two of them by the professor of the lecture and the third by a student. The analysis examines if the forms and the functions of the recontextualized metaphors are different from those in Hofstadter and Dennett's text, as a lecture is usually considered to be explanatory rather than argumentative.[11] Furthermore, I will investigate if the professor's recontextualizations of Searle's deliberate metaphors further the students' understanding of Searle's concept of the mind.

3.3 A professor's recontextualizations of Searle's stomach example analogy in a philosophy lecture

The philosophy lecture starts with a student being allowed to initiate a discussion about a topic of his choice (from the homework readings by Searle, Hofstadter and Dennett). Incidentally, the student picks the Stomach Example by Searle and reads out part of the excerpt in Example (3) above. To ease reading, I provide this part again as Example (6).

11. What I call explanatory is also called informational, for instance by Biber (2006). Biber's analysis of university lectures shows that they have "a primary informational focus" (Biber, 2006, p. 136). Even though a persuasive function of academic lectures is thus de-emphasized, this does not mean that they are completely objective. Biber (2006, pp. 116–117) also finds that lecturers, to varying degrees, convey their own stance on the content of a course.

(6) For example, ***there is a level of description at which my stomach does information processing, and it instantiates any number of computer programs, but I take it we do not want to say that it has any understanding*** .
(Searle, 2000, p. 360)

The professor, being faced with this quote and being forced to react to it on the spot, makes several attempts to explain the context as well as the meaning of this short Searle quote. In each of these attempts, he recontextualizes Searle's metaphors. All of those recontextualizations are interesting, and most of them are also problematic in regard to how adequately they express or explain Searle's view on the mind. Due to space limitations, I will concentrate on the most intriguing recontextualizations of the Stomach Example in the philosophy lecture. The first instance is presented in Example (7) below.

(7) (…) we can define the stomach in the exact same way that the computationalists define the brain. Right? ***We don't wanna say that what the stomach is doing is thought or understanding or awareness*** . Likewise, you know, since the brain is doing exactly the same thing, it's just, you know, slightly – or quite a bit – more complex, uh, it's just doing the exact same sorts of things and so, you know, if ***we don't call the stomach a mind*** , therefore we shouldn't call the brain a mind.

There are several problems with the professor's explanation and metaphor recontextualization in Example (7). In fact, the first (partial) sentence is already problematic. The professor establishes a comparison between the stomach and the computationalists' definition of the brain (i.e., the strong AI claim). While this is not exactly wrong, the comparison either blends together the target domain elements in Searle's Stomach analogy or it ignores an important step. If we look back at Example (3) and Figure 4, we can see that Searle uses the stomach to compare it to a computer, not the brain. While it is true that the brain in strong AI is considered to be identical to a computer, leaving the computer out of the explanation of the analogy ignores the metaphor A BRAIN'S MIND IS A COMPUTER PROGRAM as a target domain in Searle's analogy. However, spelling out this comparison is vital, since Searle's metaphorical argument intends to show that this comparison in the target is improper. The professor's simplification of Searle's Stomach Metaphor results in the failure to spell out the entire analogy. Therefore, the relationship between the target domain elements is not properly established, which probably leads to the troublesome last sentence in Example (7), where we find a severe misrepresentation of Searle's argumentation and also of his general view on the mind in relation to the brain.

Before the professor's misrepresentation of Searle's view on the mind, he accurately establishes the source domain of Searle's Stomach Example (first part marked in bold and italics in Example (7)). The professor then returns to the target domain of Searle's analogy (signaled by the word likewise) and incorrectly represents it. In the professor's faulty version of Searle's Stomach Example, the brain is doing the same as the stomach, just in more detail. This is the exact opposite of what Searle's analogy establishes (see Figure 4). Searle's comparison between stomach processes and brain processes does not take place in his analogy's target domain, but in its source domain. The point of this comparison in the source domain is, as we have seen, that the two processes have nothing in common, as one involves understanding and the other one does not.

While the first part of the sentence introduced by *likewise* is quite a problematic recontextualization of Searle's Stomach Example, the professor's conclusion in Example (7) takes the misrepresentation of Searle's view on the mind even further. Whereas the professor suddenly correctly repeats Searle's source domain implication that a stomach should not be considered a mind (last clause in bold and italics), he concludes that this means we should not consider brains as minds.

The professor's recontextualization of Searle's deliberate metaphors establishes a target domain with a comparison between brains and minds (the last clause in Example (7)). Such a comparison is not part of Searle's analogy of the Stomach Example, or any of his other analogies. As I established earlier, the target domain in both of Searle's key analogies is the metaphor A BRAIN'S MIND IS A COMPUTER PROGRAM and not a comparison between brain and mind. What makes this incorrect representation of the target domain worse is that throughout his paper "Minds, brains, and programs", Searle argues for a quite embodied notion of the mind. In Searle's opinion, the biochemistry of the brain is the only thing that is capable of giving rise to a mind. However, the professor's conclusion in Example (7) that "we shouldn't call the brain a mind" is quite misleading in regard to Searle's overall view on the mind.

While the misrepresentation of Searle's view on the mind (Example (7)) is rather problematic, it could be argued that this is just a brief slip-up by the professor. He may merely have mixed up elements of the analogy in this one instance. Furthermore, we do not even know if these analogies have any influence on the students' reasoning. However, the immediate progression of the philosophy lecture attests that these objections are not correct. Immediately after the professor's turn, whose end is represented in Example (7), a student challenges Searle's metaphorical analogy in the Stomach Example. The brief dialog between the student and the professor is expressed in Example (8) below.

(8) a. Student: I don't really see how food is the same as data –
 b. Prof: Uhu.

c. Student: – like, uh, isn't food – wouldn't that be more comparable for the machine being charged or something? Like its (?zest?)[12]

d. Prof: Yeah, ummm, Ken?

Example (8) shows that the student questions the accuracy of part of the mapping in Searle's Stomach Example (8a), since she cannot see how food (part of the source domain) would correspond to data (part of the target domain). The student continues by providing an alternative partial mapping (8c) when she says that the source domain constituent *food* would better correspond to the target domain element *charging of computer*, probably because both food and recharging are necessary for the organism (source domain) and machine (target domain) to function. It is interesting that the student in Example (8) reestablishes Searle's original mapping (stomach to computer) immediately after the professor represented this mapping inaccurately (stomach to brain).

At the same time, though, she also uses an aspect in her comparison that Searle does not mention explicitly, which is *data*. *Data* as one of the aspects of the partial target domain COMPUTER PROCESSES is part of the professor's earlier metaphor recontextualization. Before the partial turn in Example (7) above, the professor elaborated on the exact processes involved in Searle's Stomach Example, mentioning *data* as one of the metaphor constituents. Hence, the student's utterances in Example (8) demonstrate that both Searle's original metaphorical analogy and the professor's metaphor recontextualizations have an impact on her reasoning about the perspectives on the mind presented in the homework readings (and in the lecture).

I will address possible implications of the student's partial ignorance of the professor's metaphor misrepresentation for metaphor in education in general later on in my conclusion. For now, I want to focus on the ensuing development of the lecture. As we can see in the last turn of the example above (8d), the professor's reaction to the student's recontextualization of Searle's metaphors in the Stomach Example is to ignore the student's suggestion of an alternative mapping. The professor does not immediately acknowledge the student's objections, but instead proceeds by giving the turn to another student, perhaps assuming that the other student wants to respond to the female student's criticism. In his turn, the next student calls attention to the fact that brain and stomach differ vastly in complexity. The professor responds to that by connecting this comment to Hofstadter and Dennett's (2000b) response to Searle's (2000) article, since what the second student pointed out is precisely the difference in complexity that Hofstadter and

12. Words surrounded by question marks in brackets indicate educated guesses by the author, as the respective part of the lecture was more or less inaudible.

Dennett criticize Searle for. Rather than pursuing Hofstadter and Dennett's criticism of Searle's paper any further, though, the professor takes a step back and once again explains Searle's Stomach Example. This is illustrated in Example (9) below.

(9) But, you know, it's [stomach processes] basically, uh, you know, input, some sort of formally defined procedure, output. Right? And you know, that's the picture that computationalism gives us and that's all there is to thought, right? Some sort of input is perceived, some formally defined process is, uh, implemented and then there's some sort of output. Right? So, you know, the ***stomach takes in food from the esophagus, which then, you know, churn, churn, churn, churn, bio, bio, bio, acid, acid, acid, whatever, then output into the intestines*** . Um, and, you know, basically, if you take the computationalist model of thought at face value – that's what the brain is doing, right, it's receiving data, some formal process is implemented and then it outputs and that's all neurons are, right? It's just – they get input, do something, generate output. Um, and they're all, you know, formally defined, so, you know, if ***we don't wanna think of a stomach, which is just a collection of cells, as thought*** , then likewise we shouldn't think about the brain, which is just a collection of cells, as thought. Um, Jim, did you put your hand up?

Perhaps the professor's repetition of the explanation of Searle's Stomach Example, including much more elaborate metaphor recontextualizations (Example (9)), are a delayed reaction to the female student's challenges of the Stomach Example metaphors earlier in the lecture (Example 8)). Rather than moving on to Hofstadter and Dennett's criticism, he professor might provide this second explanation because the comment by the female student in Example (8) made him doubt that Searle's stomach analogy is completely understood yet. Another indicator that the female student in Example (8) might have triggered the professor's second problematic recontextualization of Searle's Stomach Example is that he quite explicitly presents how food relates to "what the stomach is doing". Probably in order to show that in Searle's analogy, food is not about keeping the organism functioning, the professor exemplifies different processes that food runs through when it is in the stomach (see first part in Example (9) in italics and bold). Thereby the professor reinforces the aptness of the *food-data* comparison that the female student challenged.

While this elaborate account of food processes might have illuminated the correspondences between stomach and computer processes, including the target domain constituent *data*, the professor fails to actually point this out. Instead, he reinforces the incorrect representation of Searle's stomach analogy. The first underlined part in Example (9) indicates the professor signaling a metaphorical comparison between the detailed recontextualization of the stomach part of Searle's source domain and the brain (rather than a computer). This repeated incorrect mapping between STOMACH and BRAIN then leads to a reiteration of the wrong analogy in the second highlighted part in Example (9). Again, the professor claims that Searle concluded that we should not consider the brain as thought based on differences between the source domain parts STOMACH and THOUGHT. As we saw above, this is not at all what Searle argues in his metaphorical stomach analogy. Searle's target domain in the Stomach Example does not consist of a comparison between stomach and mind, but of the metaphor A BRAIN'S MIND IS A COMPUTER PROGRAM, whose literal truth is disproved by the overall analogy.

This second misrepresentation of Searle's argumentation in Example (9) is highly problematic in such an educational setting for at least two reasons. First, the professor's repeated metaphor recontextualizations occurs at an important point in the lecture, where it is even more likely that students pay particular attention to it. As we have seen in Example (8), shortly before the professor's recontextualizations in Example (9), a student has challenged the accuracy of one of the mappings in Searle's stomach analogy. The professor's turn in Example (9) constitutes the first response to this objection by the professor himself. Other students may have waited for the professor's view on the issue and would now be more alert than usual, perhaps also paying more attention to the exact words of the professor. Thus, the incorrect metaphor recontextualization might be even more likely to be noticed. Second, unlike the first incorrect metaphor recontextualization (see Example (6) above), this second problematic recontextualization is much more detailed, which adds to its prominence. The almost graphic details of the source domain part STOMACH PROCESSES make it almost impossible for the hearers not to attend to the source domain and consequently consider the target domain (COMPARISON BETWEEN BRAIN AND MIND) from the source domain's perspective. These two problematic aspects might result in students integrating the misrepresentation into their own reasoning about the mind. This reasoning, however, is far removed from the starting point of the philosophical and scientific debate about the mind, that is, the metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM.

In the following last section of this chapter, I will summarize the path of this *computer metaphor* across the three stations considered here. I will also draw some tentative conclusions about the use of deliberate metaphors in scientific discourse and recontextualizations of these deliberate metaphors in educational contexts.

4. Summary and conclusion

This chapter examined three stations on the path of the influential metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM. The metaphor was established in the 1960s as a theory-constitutive metaphor to theorize about the nature of the mind. Later on, some researchers in Artificial Intelligence turned the metaphor into a literal truth, claiming that the mind is not just *like* a computer program, but literally *is* one. This is known as the "strong AI claim". My analysis of three points in the lifetime of the *computer metaphor* started in 1980 when Searle argued against the literal truth of this metaphor in his paper "Minds, brains, and programs".

Searle's argumentation is mainly based on a newly constructed and quite complex metaphorical analogy, featuring A BRAIN'S MIND IS A COMPUTER PROGRAM as the target domain. This analogy as a rebuttal of the strong AI claim is well-known as the Chinese Room Thought Experiment. The rich source domain scenarios (*Chinese Scenario* and *English Scenario*) of the analogy practically force the reader to consider the target domain comparison between computer programs and minds from the perspective of the analogy's source domain. Searle's other major metaphor in his refutation of the strong AI claim is the Stomach Example. This can be seen as an extension (or modification) of the Chinese Room Thought Experiment analogy. The Stomach Example is described in far less detail, but its structure is quite similar to the analogy of the Chinese Room Thought Experiment and it also features the comparison between computer processes and brain processes as its target domain. Thus, the *computer metaphor* is again at the heart of the metaphorical analogy. Both deliberate metaphors are carefully constructed to best accomplish their goal of persuading the reader of Searle's view on the mind.

The second point in the life of the *computer metaphor* that I examined took place a year after Searle's original publication of "Minds, brains, and programs". Again, the question about the literal truth of THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM is the object of an argumentative paper in the discourse of Philosophy of Mind. The philosophers Hofstadter and Dennett also address fellow experts with the purpose to persuade the reader of their view on the mind. However, their view is opposed to Searle's, granting the *computer metaphor* the potential to become literally true. Thus, their essay is a rebuttal of Searle's arguments and systematically disassembles his metaphorical analogies. Intriguingly, they do this by recontextualizing Searle's original metaphors.

The last station of the *computer metaphor* that I considered takes place approximately 30 years later and in a different discourse setting. Both Searle's and Hofstadter and Dennett's metaphorical arguments for or against the literal truth of the metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM play an important role in a philosophy lecture, as this lecture is dedicated to these philosophers' views of the mind. In my analysis of metaphor use related to the *computer metaphor*, I focused on the professor's explanations of Searle's view on the mind. Specifically, I focused on explanations of Searle's reasoning in his analogy of the Stomach Example.

Unlike the previous types of discourse with a primarily argumentative function, an academic lecture is primarily explanatory in nature. In order to explain Searle's view on the mind, though, the professor has to recontextualize Searle's original metaphors of the Stomach Example, just like Hofstadter and Dennett had to, but for different purposes. The analysis of two of the professor's recontextualizations of Searle's Stomach Example metaphors has indicated several problematic aspects. Perhaps most troublesome is the fact that the professor changes the target domain of Searle's analogy to a comparison between brain and mind. Thus, the professor loses sight of the central point of Searle's metaphorical analogies, that is, the metaphor A BRAIN' MIND IS A COMPUTER PROGRAM as the target domain. This modification of Searle's analogy necessarily results in a misrepresentation of Searle's view on the mind, as the topic of Searle's reasoning is not expressed correctly. Furthermore, with his flawed metaphor recontextualizations, the professor arrives at the troublesome conclusion that the brain and the mind are utterly disconnected. However, one of Searle's main claims throughout the paper "Minds, brains, and programs" is that brain and mind are deeply connected, as only a brain can give rise to a mind.

The professor's misrepresentations probably influence the students' concept of Searle's view on the mind. I argued that this is due to the heightened prominence of the professor's metaphors. This prominence, especially of the professor's second metaphor recontextualization analyzed here, results from detailed elaborations of a part of Searle's metaphorical analogy (stomach processes) and also from the point of the lecture at which it occurs. Indeed, my analysis of a student objection to a perceived mapping in Searle's Stomach Example showed that this student's reasoning is in fact making use of the metaphorical analogies of the texts and the lecture. Even though the student uses a metaphorical expression from the professor's incorrect representation of Searle's metaphors, which indicates that the professor's metaphor use influences her conceptualization of the topic, her reasoning is mostly based on Searle's original analogy of the Stomach Example, including the correct target domain (A BRAIN'S MIND IS A COMPUTER PROGRAM).

In light of the professor's repeated misrepresentation of Searle's Stomach Example, the student's accomplishment in not becoming confused seems extraordinary. It would be conceivable that the student "resists" the professor's incorrect metaphors, because she has a very good understanding of the original texts and a firm grasp on the complex metaphors that the reasoning of the philosophers is based on. Considering the complexity of the metaphorical analogies in the readings, though, I do not expect all of the students to have such a good understanding of the philosophers' figurative reasoning. Particularly weaker students probably have to rely much more on the professor's explanations of the two contradictory views on the mind that are expressed by the different authors. Thus, the detailed and almost graphic metaphors that the professor uses in his recontextualizations of the Stomach Example are probably quite memorable so that especially weaker students (or students who have not read the papers at all) may construct distorted concepts of Searle's view on the mind.

Of course, any claims about the students' reasoning and the influence of the professor's (or the authors', for that matter) metaphor use on their conceptualizations are speculative and go beyond the scope of this linguistic analysis. Still, the linguistic evidence that we observed also included student utterances challenging a mapping aspect of the Stomach Example. This indicates that psycholinguistic experiments investigating the influence of the metaphorical analogies in the texts (and the lecture) would probably constitute a valuable future research project. If experimental research will show that such deliberate metaphors in educational settings greatly influence the students' conceptualizations of the topic, deliberate metaphors can be a powerful tool for educators. Deliberate metaphors are a tool to make students consider a specific topic from the point of view of the metaphor and reason from this standpoint. They can thus be powerful devices to help transforming lay perspectives of students into (more) expert ones, considering the topic from multiple viewpoints. At the same time, such results of experimental studies would also mean that educators have to be made more aware of the challenges deliberate metaphors also create, since wrong mappings may lead to a distorted concept of the respective topic. Thus educators should be quite careful in their choice of metaphors and they should thoroughly prepare the deliberate metaphors that their students encounter in preparatory readings. To conclude, the present study indicates that awareness of the pitfalls and the potential of deliberate metaphors should be raised among educators, but experimental support for the linguistic evidence analyzed here still needs to be collected.

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Conclusion

When metaphors serve scientific ends

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This final chapter uses the metaphor characteristics set forth in the introductory chapter to comment on the individual studies reported here. Where the introductory chapter describes the principles of modern metaphor research that promise to improve access to science, this chapter highlights the actual application of these principles as found in the chapters of this book. When we focus on key requirements of scientific inquiry – description, explanation, and prediction – metaphor is found to be both very helpful and sometimes to pose difficulties. Such results are reviewed here, with discussions intended to benefit scientists, communicators, and metaphor scholars.

Keywords: scientific description, scientific explanation, scientific prediction, causation, groundedness, metaphor combination, abstract metaphor, generative metaphor, theory constitutive metaphor, metaphor context, propaganda metaphors

1. Scope of review

An edited volume such as this provides an opportunity to show how metaphor serves science while also contributing to metaphor scholarship. Our focus is on particular metaphor characteristics, strengths and weaknesses that may contribute to, or detract from, science and the exposition of science.

As with the introductory chapter, we address this chapter to *science communicators* (who include scientists as well as science educators, popularizers or journalists, collectively), *metaphor scholars* (experts in metaphor who study metaphor in a variety of discourses, possibly including science), and *audiences* or *audience members* (those who read about science as specialists, students, or others interested in science and its explication).

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2. Characteristics of scientific metaphors

Metaphors are indispensable for the transfer of knowledge from a source domain that an audience supposedly knows well, to a target domain that is less well understood. As is the case in all discourse, scientific discourse requires this knowledge transfer and will inevitably be metaphoric. Metaphors generally function to communicate new perspectives (often with novel forms), map from a known domain to the topic at hand to frame a conceptual structure, and shift awareness and attention to activate mappings and introduce needed linguistic terms (Denroche, 2015, offers a useful review; also Chapter 1 of this volume lays out what we believe are the principal characteristics and functions of metaphor).

The chapters collected here demonstrate wide variation in these characteristics, such features as metaphor groundedness and whether metaphors appear separately or in combination with others. We note also which scientific metaphors are conventional or novel, concrete or abstract, based on bodily or cultural experience, casually or consciously chosen. But we now raise issues that are more particularly relevant to science: Do they guide scientific exploration in a generative manner or simply characterize current findings, and how central are the metaphors to scientific theory? It will be instructive to observe how these qualities and features of metaphor relate to a central scientific concern – causation.

2.1 Selection of metaphors to study: Intuitive versus systematic

In keeping with methodological trends we identified in the introduction, contributors to this volume use corpus analysis and close reading to find scientific metaphors in actual science discourse, including published scientific papers and books, videos and transcripts of lectures, and narrated audio-visual presentations. Having focused on their chosen scientific topic or target domain and assembled a corpus of material, how do scholars select those metaphors of high value? Systematic methods exist that attempt to identify and analyze all metaphor source domains in a text or corpus (such as Pragglejaz Group, 2007), and may also detect how they are arranged in, for example, hierarchies or lattice networks (such as Shutova et al., 2013; Stickles et al., 2016). While systematic, all-inclusive documentation of metaphors in scientific discourse might be useful, our contributors make no claim to survey all metaphors that might possibly contribute to understanding. They consider the context, salient parallels to the topic that may structure similes or analogies, and the metaphors that scientists who specialize in that field of study have already put to use in specialist discourse (Knudsen, 2003). In this sense the metaphors selected tend to be deliberative, are both conventional and novel, and are more intuitive than systematic.

2.2 Three purposes served by scientific metaphor: Simple description, understandable explanation and accurate prediction

In this concluding chapter we ask how these relate to three express purposes of science: description, explanation, and prediction. For the science communicator we note which kinds of metaphors stand out as instructive and worthy of close attention in these regards, and ask whether the shift in perspective they achieve is mostly beneficial for science, pedagogy, and popularization. What about metaphors that sacrifice scientific understanding in favor of other objectives such as promotion, persuasion, or argumentation? Do science writers take steps to correct misconceptions when metaphors over-simplify or even mislead?

Description comes first in most scientific writing to provide background information on the topic to be discussed, and sometimes extends throughout if study is limited to general parameters or a summary of surface details. Greater depth is provided when scientific discourse attempts to explain phenomena and predict outcomes. These latter two purposes correspond to the distinction made by some statisticians and philosophers of science having to do with what they call scientific "models" (see Bailer-Jones & Bailer-Jones, 2002; Shmueli, 2010). They compare models primarily intended for explanation versus those for prediction. Explanatory models fulfill what scientists so often insist to be essential, showing that an observed phenomenon fits a theoretical chain or network of causes and effects, how a causal process is conceived (a process that cannot be directly observed or literally described) that results in a particular outcome.

By stating these three purposes we are not asserting their preeminence in the philosophy of science, although they are certainly important, but primarily offering a framework for discussion in this chapter. The three purposes are described in more detail below with examples. This framework comes from science, not from metaphor studies, and we will see how it might challenge current metaphor theory as presented in the introductory chapter of this book.

2.2.1 *Simple description*

Scientists typically describe their topics of interest before they attempt to show the audience the inner workings. Recall the importance of target domain background knowledge in our introductory chapter. These descriptions are useful at the beginning, as when Williams-Camus (this volume)[1] tells us what apoptosis is, before exploring the metaphors used in scientific explanation of the phenomenon, or when Amin gives us background on the nature of energy so we can better

1. When an author's name is given in the text or in a citation and no date given, it refers to that author's contribution to this volume.

understand later how the Event Structure Metaphor and various blends are used to understand it. But even these simpler descriptions involve conceptual metaphors (examples: APOPTOSIS IS DEATH; ENERGY IS HEAT). Description of this sort begins an explanation, names *what* a phenomenon is, but does not give a full account or offer much insight into *how* it works, although some regularities may be signaled. So causation is omitted or barely suggested.

Scientific description alone is nevertheless essential and its delivery influences the success of scientific discourse. Ureña reviews a number of embodied orientational and primary metaphors that are mainstays in describing scientific phenomena. They are static, visual, non-linguistic metaphors widely used in diagrams, maps, and illustrations. For example, weather and ocean currents are described using visual metaphors that map bodily sensory-motor experience such as color to the scientific abstraction of temperature (RED IS HOT, BLUE IS COLD), central location to how important a feature is conceived to be (IMPORTANCE IS CENTRALITY), proximity of objects to how correlated or interactive they are (RELATEDNESS IS PROXIMITY), the shape of a line to direction of movement (MOTION/DIRECTION IS LINES/ARROWS).

The conceptual metaphors just mentioned are very concrete. Not only are they grounded in unconsciously learned, repeated bodily experience, but also everyday conversation reinforces and entrenches them, making them familiar and conventional. Each metaphor aids description and may lead to some shift in perspective, heightening expectations of certain outcomes. In that sense it may even go beyond what is intended as description and prime an audience to speculate on cause and effect. But, as is inevitable, these metaphor source domains oversimplify their target domains and, alone, each explains only minimally how the depicted elements interact.

2.2.2 *Explanatory models and metaphors*

Explanatory metaphors go beyond description and render unseen microcosmic processes as physical and mechanical, involving movement of substances or objects. They are very much conventionalized – the source domain consists of concrete entities (substances, objects) governed by the embodied experience of force mechanics, located and oriented in space – and are conceptually coherent. They seem so natural and are taken so much for granted that they are everywhere in scientific thinking and discourse as they are in any discourse: They are "used constantly and automatically, with neither effort nor awareness" (Lakoff, 1993, pp. 227–228). Of particular interest are conventional metaphor source domains of spatial relations and locations, entities or substances that move in space on paths between locations, and force dynamics that push and pull those entities – which together structure our everyday understanding of causation.

Lakoff and Johnson (1999) bring these together when they state the conceptual metaphor underlying the conventional understanding of causation as CHANGE IS MOVEMENT – where change is the application of physical force to an object, moving it from one location to another in space. As Brown reminds us, the notion of causation is central to science. Mechanistic models in science purport to show causation (cf. Woodward, 2017) depending entirely on these same conventional metaphors. They do this by describing a sequence of actions at a micro level, one entity acting upon another entity, much as billiard balls, set in motion, strike and move each other in succession. Add to this the Event Structure Metaphor (Lakoff & Johnson, 1999) – a pre-configured cluster of conventional, embodied metaphors that convey purpose as well as causation – and it is not surprising that science writers use this powerful, generic metaphoric structure to describe a wide range of target domains.

Scientists have been known to insist on finding such explanations – grounded in bodily, sensorimotor experience, like a picture or familiar sequence of physical events – that portrays the chain of cause and effect. Without this it seems that the abstractions alone (mathematics, for example, heavily relied upon in physics) will leave scientists feeling unsatisfied. Brown (2003, p. 85) quotes Max Planck, a leading physicist of the early twentieth century, struggling to give his theories "real physical meaning." Embodied features easily become expository elements in scientific theories, that is, theory constitutive metaphors that offer easier-to-understand explanations that are invaluable to theory formation. Among contributions to this volume are examples of such explanatory models and metaphors.

A well-known example of an explanatory model, as summarized in this volume (Smith), depicted the unseen atom in terms of the well-known ATOM IS SOLAR SYSTEM metaphor. It appealed to both physicists and lay people because of its apparent clarity and specificity as to multiple elements in orbit around a central body maintained by a balance of attraction and repulsion. By so specifically depicting how elementary particles should behave, once experiments were contrived to test these hypotheses, it was concluded that electrons did not, in fact, travel in orbits around the atom's nucleus. The metaphoric model was abandoned by scientists and new explanations sought.

Another example of an explanatory model is social field theory (also described by Smith), the central metaphor of which is SOCIAL PROCESS IS FIELD OF FORCES. Human social interaction is depicted in terms of the causal interaction over time of the entire network of relevant psychosocial and environmental factors ranging from micro to macrocosmic levels. The source domain FIELD OF FORCES was carefully chosen by theorists and seems deliberately to invoke conventional, concrete notions. The obvious Newtonian inferences, as per the sub-mappings identified by Smith, portray social factors as objects arrayed on physical terrains, impelled to interact. Yet field theorists correct this misconception with literal language to the effect that the FIELD OF FORCES is an abstraction and the nature of such forces (perhaps like gravity or magnetism) is definitely not like embodied mechanical force. The theory has been very difficult to test empirically in its idealized form. With the advent of detailed computer simulations parts of the theory have been explored, metaphorically conceived as an ADAPTIVE DYNAMICAL SYSTEM. The theory's principal value has been to shift audience viewpoint so as to consider a much wider range of interacting, causative social factors operating at both micro and macro levels – not to predict snapshot outcomes – but more likely to give (perhaps only to hint at) an explanation of the change processes unfolding in the target domain over time.

2.2.3 *Predictive models and metaphors*

In the science of physics, at least, despite an historical preference for explanatory physical conceptualizations, what seems to have become more important is accurate prediction. Currently, if there were to be a contest between explanatory, conceptual understanding and accurate predicting, predicting would win. Physics gets its best predictions through the statistical reasoning of quantum theory and thermodynamics, even though these lack the concreteness and appeal of conventional, embodied, mechanical reasoning (Mikulecky, 2005). A modern theoretical physicist (Beretta, 2009, p. 2) decries current attitudes (compared to those of Max Planck, above) when he notes that statistical reasoning has "enjoyed such great successes that the power of its methods have deeply convinced almost the entire physical community that the conceptual problems can be safely ignored."

While mechanical models based on conventional, embodied metaphors may fail to predict accurately, we see that they often continue to appeal. Their ubiquity indicates that science writers generally find advantage in their use. We saw this already in the case of the solar system model of atomic structure, which is a mechanistic analogy understood in terms of highly conventional, concrete metaphors. But these did not predict what later experiments revealed about the atom. So the mechanistic depiction was demoted in favor of quantum theory which did account for experimental results. Yes, prediction won and the mechanistic, explanatory model was demoted, but it still has uses and lives on in popular discourse and elementary physics texts. This is deliberate and purposeful on the part of science writers.

We saw this again in Amin's chapter where students are taught about energy. In one sense explanatory models may seem in competition with predictive ones. In another sense they work in tandem. These actual science examples of deliberate metaphor show the challenges that metaphor theory faces, and why some of the deliberate metaphor theoretical issues discussed in our introductory chapter remain unresolved. Of particular interest are highly conventional metaphors, automatically introduced when science is explained, and later intentionally and consciously retained for expository purposes.

The Event Structure Metaphor is central to much of everyday human conceptualization. Amin reveals it depicting fictional causes for how energy works, and we see again how such a conventional, mechanical model endures even when it contradicts settled science. Recall that energy is not a "thing" or an object that behaves like billiard balls. It is a fundamental abstraction in physics, properly accounted for using entirely different principles and for which no mechanistic metaphor provides a comprehensive understanding. Nevertheless certain conventional, mechanistic metaphors are found used both by students and scientists in a pattern or sequence that narrates how energy may seem to work and prompting useful computational steps that lead to accurate predictions in certain kinds of cases. The conventional notion of the transfer of energy is metaphorically understood as a substance passed from one entity to another. Being concrete and grounded in sensory-motor experience, involving mechanical movement of substances, such metaphors end up simplifying and communicating knotty chains of scientific reasoning.

Amin shows the systematic use of multiple sub-mappings of the embodied event structure metaphors, such as to quantify energy (ENERGY STATE IS AMOUNT OF SUBSTANCE) and to think about and explain changes in the energetic state of a system, such as energy transfer and conservation (CHANGE OF ENERGETIC STATE IS MOVEMENT INTO [OR OUT OF] A CONTAINER). These attractive mechanical conceptions are recruited for use in instructional materials and found in transcripts of student problem-solving sessions.

As mentioned, these metaphors actually contradict established theory in physics. They operate unconsciously for general audiences although introduced deliberately by specialists because the inference structure helps non-specialists reason about the topic. Physicists accept scientific metaphors that are known to be misleading but offer the means for accurate prediction, are treated as necessary aids in teaching, then qualified when it is appropriate to explain current scientific understanding more fully. This would seem to fulfill the "stepping stone" or "creative falsehood" function of scientific metaphors, so long as such metaphors are actually discarded after the teaching function is complete (Steinhart, 2001, p. 7). Evidently they are not discarded, as attested by Amin's quotations from eminent physicists.

So we see in practice the reverse of the "change in perspective" that one hopes good scientific metaphors will provide: Instead of helping students understand a difficult topic, a metaphor is used that bypasses the difficulties by *not* shifting perspective or altering customary viewpoints about complexities. These science writers must realize that misconceptions will eventually have to be addressed for those seeking deeper understanding of the topic. When combined and sequenced with other metaphors they communicate and explain usefully; because of this they are retained. This is an example of the allure of accurate, quantitative prediction.

The allure of prediction is observed in the social sciences in a different manner. Computational data analysis models aim to accurately predict the outcomes of complex processes. Smith asserts that such models are based on metaphor; their core metaphors have become concrete and conventionalized for the scientists dependent on them, but to others they are abstract, even inscrutable. The computational models are general-purpose routines "trained by" or "fitted to" the data so as to make the most accurate predictions, that is, what an outcome is most likely to be at specified points in time. Regression analysis and neural networks are examples of data analysis techniques useful in refining predictive models. Conceptually this approach omits theories or representations of real-world dynamics or processes involved in producing outputs, and substitutes data structures and the processes of computation. They are optimized for specific applications. Consequently they are of less value in development of scientific theories concerning the topic being studied. Another example is the mathematical model of the atom that probabilistically predicts locations of atomic particles where the solar system model fails to do so (Smith); it substitutes (in this case) mathematical structure for physical structure or experiential gestalt. The predictions are accurate in terms of the laws of quantum theory. But the metaphor source domains are not what conceptual metaphor scholars might expect.

Audiences fully familiar with the mathematics may metaphorically use the math in a predictive model as an abstract source domain for the physics target domain; as discussed in the first chapter, this reverses the more common relationship found with conceptual metaphors where the source domain is concrete and the target abstract. Smith describes another such example, the DATASET metaphor, used by social scientists who focus on violent macro aspects of law enforcement, relying on the metaphoric structure of their statistical reasoning and largely ignoring the social dynamics that may cause the results they find. In order to grasp why black people are more often shot by police than white people in the U.S., the audience must join the social scientists as they map structure from multivariate regression equations to the target domain of social process. Such mapping may seem forced, but note that the social scientists, having mastered their computational tools at a concrete level, can explain in detail how the equations have traceable correspondences to their extensive and carefully coded datasets. The dataset and regression statistics become a concrete source domain for these scientists and this may satisfy a desire for "real physical meaning" at an embodied level. Smith indicated how such computational source domains influence scientists' to adjust their computations, such as adding new terms to equations. This substitutes for the generative effect or new ideas expected of scientific metaphors. If this satisfies the social scientists, the source domain remains abstract for the non-specialist audience who continue to wonder about the social processes that result in violence.

When the source domain is as, or even more, abstract than the target domain, "this makes these metaphors somewhat marginal instances of metaphor" or not even like metaphors at all (Kövecses, 2005, pp. 266); while the quantitative predictions are expressed by the mathematics, the scientific process seems unexplained – cause and effect are not conceptualized – and whether they adequately guide scientific exploration remains an open question.

2.3 Social models and metaphors: A level of scientific analysis where physically embodied metaphors may not work

In biology, to the extent that explanations reduce to mechanistic conceptions of classical physics and chemistry (such as individual cell nourishment, elimination, energy production, cell division), these unseen microcosmic biological processes have historically been understood metaphorically and grounded in OBJECT, MOVEMENT, SUBSTANCE, and CONTAINER (Liu, 2016).

But much of biology cannot meaningfully be reduced to underlying principles of physics and chemistry. This is because of the long chains of unseen micro-events that are untraceable or too intricate or overwhelmingly tedious to summarize, thus relatively useless as explanation or a depiction of causality. At the microcosmic level individual cells are containers of chemically generated protoplasmic substance that reproduce through physical division. But, as Brown points out, cells combine to form differentiated organs with distinct functions at a macro level. So more macro, abstract social source domains might best be used to summarize and characterize these biological functions.

Social metaphors need not be vague if they are understood in terms of actual, concrete experience, as discussed in the introductory chapter to this volume. For example, GROUPTHINK might be vaguely recognized by most people, but relatively few recall having experienced it, much less formed a gestalt. So, for them, this source domain would most likely explain little and predict nothing. Such variation should prompt science writers, if they are to use social metaphors, to select those with source domains that are very common and widely experienced. Otherwise, as seen below, audiences must be carefully instructed on details of a particular source domain.

Social source domains offer a macroscopic view and, in general, their use makes quantitative predictions as required by physicists unlikely. But their explanatory power may point in new directions and can guide scientists to look for certain kinds of evidence as they study their fields of interest; creative, novel, alternative conceptual interpretation becomes more likely (Kövecses, 2005).

Micro-organisms are so small and primitive that they, as individuals, might survive, but not thrive. However, in very large groups they can dominate. Brown describes a target domain where certain micro-organisms reproduce benignly and then, only when there are enough of them, release toxicity and overwhelm the host. Brown offers another target domain: Several different strains of micro-organisms together form a biological film, each strain secreting a constituent substance sequentially in a complex series of steps, forming a hard surface that protects them. How this happens is not directly observable so must be inferred metaphorically from, in this case, the known behavior of human social groups that perform complex tasks. Brown's discussion shows biologists' creative choice of a framework based on social metaphors rather than biological mechanisms reduced to chemistry and physics. Directly mapping the social source domain to a biological target domain appropriates social terms for use in biology.

Social metaphors, depicting a higher macrocosmic level become the basis for metaphoric source domains such as COLONIES, COLONIZERS and QUORUM SENSING. Single-cell organisms are then seen to form groups, communicate through signalling and sensing, and ultimately cooperate to their mutual benefit.

Note that such metaphor source domains are not necessarily concrete, the language used is abstract and fails to evoke a reliable experiential gestalt. In the absence of background knowledge that makes source domains properly understood or even familiar, misconception can occur (Cameron, 2003). This is the case with QUORUM, a source domain vague to some, which requires the science writer painstakingly to describe what a human quorum is, along with its communicative properties and purpose in deciding action. All this must be laid out before the audience might come to appreciate the novel perspective that a deliberative human grouping as source domain brings to the target of collective behavior of micro-organisms. As Brown describes, this and other social metaphors have pedagogical value as well as their own inference structure which, in turn, has helped scientists form hypotheses as to what to look for next.

While making explanatory sense these social metaphors do not help quantitative prediction. But they do invoke sub-mappings of JOURNEY, COMMUNICATION, THE COMMON-GOOD, and COOPERATION, suggesting what to look for at a macro level (such as toxicity-sensing capability in each micro-organism). It is from these sub-mappings that the audience might infer a teleology that organizes millions of micro-organisms as an intercommunicating, unified whole, even though such inferences are mistaken and epistemologically confusing. Nevertheless, when at first novel, they succeeded in generating hypotheses, prompting biologists to look for the necessary signaling processes. The hypotheses were productive, scientists found that the signaling processes did indeed exist, and the social metaphor became theory constitutive. But in time the status of such metaphors may change.

In fact, such social metaphors in biology have proven so useful, as Brown reports, that their linguistic expressions have become commonplace in biology. "Quorum sensing" once having entered the biology lexicon, established itself in the specialists' vocabulary as a technical term and convenient label,[2] communicating precisely the specific meaning already assigned. When this happens we have seen that there is danger of metaphors becoming closed (Knudsen, 2003) so that source domain features are no longer mapped to the target (Semino, 2008), in which case they tend to be taken literally; they no longer promote any new perspective or guide scientific exploration in a generative manner. Causation could be interpreted anthropocentrically when it should be "microbe-centric". Will this undercut explanatory usefulness or lead to audience confusion despite, as Brown points out, their popularity stimulating an abundant flow of new experimental evidence?

So far, metaphors have been presented individually, but it is clear that a metaphor seldom if ever operates alone. There are inevitably combinations of metaphors or other figurative elements, such as background metaphors or cultural narratives, that frame the discourse.

2.4 Groupings of metaphors

Often, not one, but multiple metaphor source domains are needed to cover all important facets of an unfamiliar scientific target domain. But how might each relate not only to the target domain, but to each other? These are issues studied by metaphor scholars but probably seldom considered in any detail by science writers, even though metaphor combinations are key. A variety of forms are discussed in our introduction, and specific examples appear in chapters of this book.

Williams-Camus investigates several metaphors used singly and in combination by scientists and science writers to describe apoptosis, the natural occurrence of cell death. Note that it was necessary first to describe the notion of cell death (the target domain) to readers before giving the linguistic evidence of metaphor source domains that potentially explain how apoptosis works. As reviewed in our introductory chapter, this situation is common in scientific discourse generally because, except for specialists, the intended audience may be unfamiliar with the scientific topic being discussed. The science communicator must somehow assess

2. The number of biological links found on internet search engines after entering "quorum+biology" as the search term is approximately 500,000; note that definitions now given in the results of such searches are highly technical, have only direct referents and no figurative meaning, as Knudsen (2003) would have predicted.

the general frame, that is, find out approximately what the audience already knows and doesn't know, perhaps also what the audience knows it doesn't yet know, making it especially ready to learn. Using the language of mental spaces (Sweetser & Fauconnier, 1996), target domain background knowledge defines a mental space to which source domain structure can be transferred.

In Williams-Camus' case APOPTOSIS IS CELL SUICIDE would be considered novel in the context of biology. The very conventional DEATH metaphor is not embodied or physically experienced by the living, but a culturally disseminated notion, and mostly in terms of its association with (usually negative) emotions or images in social experience. CELL SUICIDE is widely used even by scientists discussing apoptosis and seems successful as a term that attracts attention and promotes interest in the subject. But not only does this metaphor fail to explain why or how, or to predict when, a cell will naturally die, it also mistakenly implies a self-imposed, shameful, hurtful, unnatural passing. So, while this metaphor is used in ostensibly scientific discourse, is it scientific? Scientific investigation shows that apoptosis is a necessary process that, should it fail to happen, leads to uncontrolled cell growth and cancer. Fortunately APOPTOSIS IS CELL SUICIDE is not used alone.

One of the other metaphors often used at the same time does more than simply complement or supplant the SUICIDE metaphor. APOPTOSIS IS PROGRAMMED CELL DEATH, avoids the idea that cells somehow may choose to die or are agents in their own early demise, and instead that death at the right time is built-in and appropriate. Furthermore it has the generative effect of prompting scientists to look for (and make very useful discoveries about) the nature of the programming and how it is controlled. When these metaphors are used together in the same writing the result could be interpreted as a conceptual integration or blending (Fauconnier & Turner, 2002; Kövecses, 2005) of concept spaces coming from each domain; is this what the audience ultimately understands? Their juxtaposition projects drama to the target domain (voluntarily dying so young!) while immediately modulating misinformation (death fits in a larger and generally healthy pattern).

Note that these two metaphors have the same target domain; their conceptually fragmented source domains both deal with death, but they are neither hierarchically organized nor conceptually aligned. Williams-Camus considers the contribution to understanding that each metaphor might make individually, reviewing the mappings found in corpora in two languages, and how they compare for scientific and science education purposes. Alternatively we may speculate that the aptness/inaptness of various mappings, while misleading to some, propagandistic or fictional, result in a dissonance that may actually highlight key aspects that scientists face in understanding what remains a mystifying scientific phenomenon. For example, blending or integration of source elements from PROGRAMMED with those of SUICIDE suggests the notion of a predestined flip-flop from wanting to live to wanting to die; or that death is not a matter of some failure in the present, but occurs at a pre-specified time regardless of concurrent circumstances. This conceptual integration seems to have been operating for scientists hoping to reverse cancerous cell reproduction by searching for ways to promote apoptosis: They looked for what caused, or failed to cause, the pre-specified time for tumorous cells to die.

Such metaphor integrations may be only temporary and dependent on context; they are ephemeral in the sense that they leave an impression more than make a statement. So they are not unlike multi-modal metaphors in some advertising and cinema that appear incongruent at first but may, after a short interval, blend in unforeseen ways (Forceville, 2016). While dissonant combinations of scientific metaphors might be understood and consciously intended by science writers to produce such effects, this doesn't appear to be the case for those writing about apoptosis. If science writers were metaphor savvy, and took some care in metaphor selection, wouldn't we expect, not dissonance, but metaphors that are conceptually aligned?

For conceptually aligned scientific metaphors, consider Ureña's account of the multi-modal metaphors (visual, auditory, as well as verbal), presented via modern video technology, that are used to teach marine biology students about certain under-sea creatures. The impact of this multi-media scientific discourse dramatizing natural phenomena is maximized through cinematic refinements of timing, sound volume, and content selection combined in scenes of gritty, live action. Its impressive strengths, as well as epistemological weaknesses, become evident.

In this example the very conventional source domains of LOUD SOUNDS, SOCIAL CONFLICT and WAR are taken from the instantly recognized and potent source domain of human society and used to explain the nature of these marine creatures and to predict what they will do next. This example, along with those of microbe quorums and cell death, above, are eminently capable of instantly shifting audience's perspective. But they imply notions of anthropocentric subjectivity and human group dynamics. Correspondingly, sub-mappings such as PURPOSE, CHOICE, KINSHIP and STATUS inevitably structure these metaphors and can create expectations in the audience. To what extent do these map true and useful correspondences versus fictive and misleading ones? Are we to understand that sea creatures intend to frighten their adversaries, that they choose which ones to fight based on species differences? Does the understanding we gain from these metaphors suggest how to predict future behavior or that of similar species?

Nor is it clear, even though the manner of exposition rivets attention on the source domain, that the communicators who produced these materials have deliberately chosen the metaphors for their scientific pedagogical value. A deliberative marine biologist wouldn't wish that the causes of animal behavior be understood as the emotional causes of human behavior, or to predict their actions always to consist of fighting, dismemberment and death. Such interpretations are extreme simplifications, they risk relegating scientific conceptual metaphors to the status of ornaments and, in addition to how they may mislead the audience, have no obvious value in guiding scientific exploration.

We might expect that the metaphor-savvy science communicator will anticipate how particular conceptual sub-mappings interact and then (hopefully) will compensate for misleading blends. For science communicators this suggests that these videos might best not be left to stand alone, but that some kind of integration with other, perhaps linguistic, metaphors that accompany the auditory and visual ones, should be contrived. In this case linguistic metaphors were included also, namely, WEAPONS and WAR, but they seem only to align with the non-linguistic ones, amplifying them. It would certainly be desirable to offer a broader interpretive framework, as occurs with some of Ureña's other multi-modal examples. Science writers who are trying to attract the attention of bored students may ignore such issues, but those intent on clarity, accuracy and causality cannot.

2.5 Metaphors for argument and propaganda

Here is an example of the use of multiple micro-level metaphors to characterize a macro state of affairs. It is instructive both because of its success as scientific metaphor and what many would say is misuse of metaphor. Von Wülfingen tells the story of a very complex biological target domain, human reproduction, in the context of an unusual shift in public opinion from a restrictive to a more favorable view of human reproduction technology. Conventional metaphors from both embodied and cultural domains are shown to play a key role, as is the manner in which they are deployed and related, one to another, to heighten their saliency and help the lay audience comprehend target domain complexity.

Fruit cultivation is used in the attempt to convey that technological interventions in human reproduction are clear, simple, natural and beneficial – HUMAN REPRODUCTION TECHNOLOGY IS CULTIVATION OF FRUIT. Botanic metaphors are conventional, concrete and a matter of daily experience at least for some audiences today, if less so now than in the past. Note how the metaphors make human reproduction – a highly complex life process – seem distinctly mechanical. It could be argued that the target domain of the metaphor is not so much the technological process of ameliorating human reproduction as it is the steps to advance it in a prescribed way. Considered in this way, the fruit cultivation metaphor describes mechanical onward motion to complete a task: choose the bedding plant (embryo, examine and perhaps edit the DNA), implant it in garden (uterus), care for it and then harvest – radically simplifying and concretizing a complex process.

The CULTIVATION OF FRUIT metaphor is combined with other conceptual metaphors that also are conventional and easy to understand, mapped to the same target domain. They exhibit complementary interrelationships among themselves that provide an ideational context for the complex topic, and then we see them neatly situated together within a dominant cultural narrative. This intertwining of metaphors leverages their power to advance a deliberate propaganda initiative: Reproductive technology is advantageously framed as timely and important, making its exploitation seem like common sense. Note how the conventional botany metaphor explaining human reproduction (metaphorically understood as FRUIT), combines with offspring characteristics being determined by DNA (TEXT) which, left to chance, involve danger and risk (ROLLING DICE), then overcoming the risks through scientific management (OBJECT MANIPULATION) of the human reproductive process. This is a JOURNEY, involving VISION of the future, bound to give superior results. The latter three source domains are grounded in embodied experience, operate unconsciously, and require no preliminary description. The first four are learned from conventional cultural experience but their value as source domains is increased by offering background knowledge – factual statements about the reproduction process.

Persuasion in this case is enhanced by a worldview that need not be stated explicitly, is not found in the corpus texts, because it is pervasive in the culture (a kind of background or necessary metaphor – key to a particular understanding even without restatement or verification). This worldview dates from the Age of Discovery and the beginnings of the Scientific Revolution and is still affirmed today – the utopian cultural narrative promulgated by influential Renaissance figures such as Francis Bacon who elevated human choice and ingenuity in determining destiny. It encourages us all to see ourselves capable of escaping nature's arbitrariness, deciding what we want, and taking steps to get it. The result of this layered formulation shows conventional metaphors found in contemporary texts dealing with this target domain, interpreted within the context of historical and cultural allegory, yielding an effective argument.

The metaphor combination might be regarded as much more compelling than the sum of the individual metaphors. Discussing them in this way suggests that, if purposefully deployed by science writers, they can successfully shift public opinion. The metaphors do not benefit scientific theorizing and are not theory-constitutive. Even minimally informed lay people know that babies are not like plants, DNA is not text, and even the best technology cannot assure risk-free wish fulfillment. The contrasts between metaphor use in science and metaphor use in persuasion are thus highlighted. While they give a macro view of a complex topic, they do not properly explain human reproduction nor fully describe technological interventions, so they lack both predictive and explanatory power. They may instead breed troublesome misunderstanding. Whether all audiences realize they are receiving a promotional message is unclear. Should not science writers provide a warning in such cases and, at least, footnote possible misinterpretations?

2.6 Macro metaphors and argumentation

What might be better able to give a macro view of a complex scientific topic, be theory-constitutive and also enable scientific explanation and prediction? To explain complexity at the macro level – to try to take in the whole of a complex phenomenon – an inherently more complex source domain may be needed. A source domain useful for complex topics will itself be complex, abstract, and may not initially be well understood by the audience. An oft-used such source domain is the machine and today's premier machine is the computer – available as a highly structured metaphor with many possible interrelated sub-mappings.

As another example where we learn from less-than-optimum use of scientific metaphor, Beger offers a revealing history of a theory-constitutive metaphor in neuroscience. It is the now very common COMPUTER IS BRAIN metaphor, in particular, A BRAIN'S MIND IS A COMPUTER PROGRAM. A matter of lively debate originating fifty years ago, the COMPUTER IS BRAIN metaphor is now entrenched and often believed literally true among those who may know relatively little about either brains or computers. We learn of deliberate metaphors, presented as elaborate philosophical analogies, constructed for argumentative purposes but scarcely explaining the subject matter. Used in three discourses with the same target, it is a unique opportunity to examine deliberate metaphor, communications function, and metaphor recontextualization.

A conceptual metaphor for which the source domain is vague or ill-defined, over-simplified, or idealized, can generate varying interpretations that become susceptible to disputation, and thereby lose informational value. In this case background knowledge of the COMPUTER PROGRAM source domain ought to be, but probably isn't, assured.

For most people, understanding the brain metaphorically as a computer is not grounded in bodily experience or universal gestalts. The source domain, COMPUTER PROGRAM, is certainly very abstract in that there are so many variations among computer programs, their structure and features. The ubiquity of computer devices today does not offer experience with the inner workings of computers but with their interfaces that don't actually exist inside the computer (Laurel & Mountford, 1990).[3] How, exactly, is this source domain to map onto what "a brain's

3. Interfaces themselves are deliberate metaphors contrived to invoke familiar real-world schema (such as the "desk-top").

mind" consists of? Whatever blend of source and target that occurs can be idiosyncratic and relatively useless as scientific explanation if it omits an understanding of the dynamics or processes involved. Of course, at the very least, we identify a rudimentary metaphor of a mechanical, industrial machine that accepts inputs and produces outputs. Taking that as literal truth may be likely to occur.

Because this source domain is not concretely experienced or culturally learned (except perhaps for a small audience) the author who initiated the debate gave a description of the source domain, carefully contrived and articulated as a lengthy hypothetical task. Still it may not have been clear in readers' minds. Whether or not BRAIN'S MIND IS A COMPUTER PROGRAM is accurate as analogy was debated over decades and Beger shows how advocates have taken it out of its original context and modified it for argumentative purposes as the disputation continues, and later recontextualized it for educational use in a different discourse event. Nerlich (2007) notes that different scientific metaphor source domains, but with the same target domain, will vary considerably and that a given one will gradually shift depending on how it is used and reported. This seems to be what Beger has found to have occurred. Kövecses (2015, p. 31) describes intertextual reuse of metaphors and characterizes such shifts as "usurpations of metaphor against our original intentions … turning [our] metaphor against us in a debate over contentious issues."[4]

This is a paramount example of metaphor in science because it shows that even contrived scientific metaphor, constructed hypothetically and inaccurately mapped, has explanatory power when the audience is induced to try to follow the mappings and to understand. This metaphor has bred misconceptions but evidently raised issues well enough for scholars to retain it for decades, use its distinctions and argue its aptness as analogy. We may deplore certain authors' opportunism to score points by repurposing their competitors' metaphors, stretching and elaborating the source domain to further their academic argument. Still, having worked through the arguments, many of which are based on distortions, and noting the array of issues it raises for metaphor studies, the reader will be much better informed about the topic under discussion, if still not understanding

4. What would be required of this metaphor to generate ideas about brain function? Only for those steeped in microprocessor operation, transfer and storage of signals, and the reusable functions and subroutines that transform inputs into outputs, might this metaphor be useful in describing, explaining or exploring the brain; for example, simultaneous activation of multiple parts of brain metaphorically understood as parallel processing in different components of a computer, generation of emotion understood as signal transmission and information integration, sub-parts of human behavior metaphorically understood as computer subroutines and functions (Marcus, Marblestone & Dean, 2014).

how the mind works in any comprehensive way nor being able to better predict what it will do.

3. Some conclusions

Briefly, here are some of the things covered here that may (1) help a range of science communicators engaging in science, pedagogy, and popularization to better use metaphor in making science more accessible, and (2) help scholars to advance the study of metaphor.

With such a wide variety of ways that science has been presented, almost any of them offer an opportunity to study metaphor. Contributors to this volume analyze conventional science writing, science infotainment, scientific charts and diagrams, science-related propaganda, arguments about science, and each of them offer their own special window into the nature of metaphor. The assortment of scientific disciplines treated here demonstrates, should anyone doubt it, that metaphor is important in all of these and more.

At an earlier time scientists and philosophers insisted that metaphor had no place in scientific discourse, nor was it legitimately to be found, because metaphor was fanciful, ornamental, and might be entertaining but could not tell the truth (Williams Camus, 2015, reviews this p. 247). With Conceptual Metaphor Theory came a recognition of the importance of metaphor in expressing scientific concepts. And corpus analysis of the actual scientific writing of specialists, teachers and popularizers showed how widely metaphor actually occurs and how advantageous it is. With the use of metaphor in science having been legitimized, attention to the details of actual scientific discourse also documented how often metaphor is exploited for the purposes of promotion, propaganda, entertainment, and argument, often at the expense of scientific "truth-telling" and accuracy. Metaphor scholars contributing to this volume attest to this, as commented on above.

Would it be radical to insist that science writing put accuracy first, and that exceptions to this dictum be accompanied by cautions, warnings, corrections, or alternative interpretations? Metaphors used in science writing would then be judged according to certain standards that might not apply to metaphor use in other fields. We have argued here that metaphor should, as top priorities, serve scientific description, explanation, and prediction. Some may prefer to prioritize other goals such as exploration, empiricism, or classic forms of the scientific method. Any such set of priorities will imply in turn their own list of standards that metaphor should strive for if it is to be helpful in scientific knowledge transfer.

In what ways can metaphor scholars particularly help science communicators to make science more accessible? Might science writers be expected, as suggested by some contributors, to become more metaphor-savvy, conscious of how metaphors work and skilled in their use? Metaphor scholarship as presented here documents the ease with which conventional, concrete, embodied metaphors convey useful information, how combinations of metaphors, including visual and auditory ones, enhance understanding, the pitfalls of abstract source domains, and the ways that misconstruals might be avoided or corrected. Social and cultural gestalts are a rich source of structure that metaphor scholars might help science writers deploy, again with precautions to avoid audience misunderstandings. Science writers might use metaphor combinations more openly, that is, remind their audience that metaphors are, in fact, deployed and show how they interact. The difficulties and advantages when metaphoric vocabulary enters a scientific lexicon is another matter illustrated here that science writers should understand. Because so much metaphor is used unconsciously – and effectively – would being consciously savvy actually be better?

When used in science discourse, how effective are metaphors in transferring knowledge? Most analyses make this evaluation based on the structure of metaphors found present, the inferences the metaphors might make possible regarding a particular target domain, the terminology introduced by metaphors and adopted by scientists, or how long the metaphors have been retained and continue to appear in a particular discourse. In this volume we find that metaphors in popular media are said to change public opinion (von Wülfingen), although there was no comparison group with which to judge the effectiveness of metaphors in the context of other factors; in another chapter there are careful assessments of how key metaphors in science education are relied upon in instructional texts, transcribed problem-solving discussions, and in the seminal writings of leaders in the field (Amin). Although not referred to here, there is literature relevant to deliberate metaphor that experimentally examines analogical learning and problem solving (such as Gentner et al., 2003). So the tools exist to evaluate metaphor effectiveness in science. The results of such evaluations could be key to improving scientific discourse and invaluable to metaphor scholarship.

But what about helping audiences more directly? Can metaphor scholars help audience members learn better from the scientific metaphors they encounter? Much has been said about how science communicators use metaphor and how they might use it better. But such discussions seem to assume that, while the communicator can adjust metaphors to meet an audience's level of knowledge or their possession of different kinds of learned gestalts, they always seem to assume that audience members are passive recipients unable to actively notice and reflect on the metaphors fed to them. They might learn close reading techniques to become aware of when metaphors are being used and the best ways to interpret them separately or in combination, the spectrum of inferences conveyed, which are intended, not intended but novel and useful, intended or not intended but misleading, and how they relate to literal parts of the discourse.

Metaphor scholars can learn much from the studies found here and the questions they generate. Discourse among specialists, as well as that directed to the public, benefit from grounded metaphors that are salient, vivid, concrete, and memorable. Metaphor scholars might look to see if, in general, metaphors used for description and explanation are mostly concrete and embodied as found in studies reported here, and if those used to aid prediction are more abstract and require a higher level of audience background (technical, mathematical) knowledge. How widespread are the temporary, creative fictions that use concrete embodied metaphors as stepping stones to more complete understanding? Are their fictional elements usually revealed in due course, or is the audience left to sort out distortions on its own?

The various ways depicted in scholarly writings that metaphors work in combination, as briefly reviewed in the introductory chapter, were often difficult to identify in the studies presented here. Since different kinds of combinations so clearly influence audience understanding, more metaphor scholarship on this subject is needed. When social source domains are used, does personification and anthropomorphism, besides creating interest, lead to permanent misunderstanding or even magical thinking?

Do scientists, when using metaphors judged to be closed and reduced to literal, technical meaning only, find them no longer inspiring of new hypotheses? Or, even though having become technical terms, do they still possess generative qualities that may pose new scientific hypotheses? Existing literature (Knudsen, 2003) indicates that they are still useful for changing viewpoints of non-specialists. Reported here is the tendency on the part of journalists to use scientists' metaphors, occasionally extending them to include more colloquial linguistic variants. This raises questions about the real nature of a "closed" metaphor and whether extensions or linguistic variations may restore their metaphoricity.

When metaphors are used for special interest promotion, or for debate and argument, does this help with scientific understanding, or merely stimulate audience attention. Does the inducement to follow tortuous inferences coming from promotional or argumentative metaphor somehow teach about a target domain accurately or usefully, despite the inferences being partially or wholly fictive? Scientists and communicators may be well advised to avoid application of metaphor for propaganda and argument. But we saw in accounts given here that such persuasion campaigns or academic debates, when in progress and having engaged the audience, seemed to serve science in certain ways. If explored by metaphor scholars, this, like so many other issues raised in this volume about science, would greatly expand our general understanding of metaphor.

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Index

A
abduction 61–62, 68–69
abstractions 19, 74, 77, 187, 216, 300–302
see also concepts, abstract
see also metaphor, abstract
accuracy, scientific 21, 63, 98, 288, 290, 310, 314
activation 17, 26, 203, 250
adaptive dynamical systems theory 240, 245
see also dynamical systems
Alberts, B. 45, 66, 67, 69
aligning source and target features 10, 15, 19, 23, 308–310
alignment of qualitative and quantitative reasoning 90–91, 93, 100
allegory 120–121, 128–130, 311
ambiguity 129, 145–146, 163, 246–247
Ameisen, J. C. 144–146, 156–157, 163, 169
Amin, T. 29, 73–74, 79–80, 85, 87, 88, 91, 94, 96, 99, 102, 104–110, 299, 302–303, 315
amusing 30, 190–191, 195, 203–204
see also entertainment
analogies 8, 11–12, 14, 21, 23, 25, 28, 33, 36, 74, 103–105, 107–110, 135, 263, 266–267, 269–271, 280, 282–284, 287, 291–293, 298, 312
analogy source domains 12, 14, 20, 105, 284, 290–291, 302
analogy, instructional 21, 103–105, 107, 167, 266, 272, 279–292
analysis, comparative 84, 89, 93–94, 101, 107, 114, 122, 142, 167–168, 266, 268
analytical tools 76, 106, 228
animal behaviour 187–188, 190–191, 193–194, 199, 203, 309
see also zoosemiotics
animal cognition 191–192, 203
anthropomorphism 146, 316
apoptosis.
see also cell death
metaphorical expressions for 142, 151–152
process of 141, 143, 148–149, 153–158, 165–166, 168
aptness 289, 308, 313
argument, academic 194, 199, 264, 267, 271, 278, 280, 283–285, 291, 299, 311–313
argument, propaganda 11, 43, 244,251, 256, 276, 280–282, 284, 310, 312–314, 316
Aristotle 14, 46
arithmetic operations 220, 222
articles
popularised 67, 148–149, 151, 155–156
scientific 10, 116, 141, 168, 183, 263–264, 285
artificial intelligence 263–265, 271, 276, 291, 293
artistic domains 15, 18
assets, field theory 234–235
astronomy 240, 252, 255
atoms 12, 49, 75, 79, 83, 213, 251, 301–302, 304
attack 151, 152, 157, 163–164, 190, 199
see also metaphor, war
attention 7, 21–22, 24–27, 66–67, 83, 144, 154–156, 192–193, 198–199, 234, 245–246, 251–252, 268–269, 290, 298–299
audience misunderstandings 19, 315–316
see also epistemological confusion
audience, non-specialist 10–11, 20, 26, 30–31, 177, 191, 194, 201, 203, 305
auditory metaphor 28, 30, 175, 196–197, 199–202, 204, 309–310, 315
autoinducer 55, 60, 63
see also signalling
autophagy 159–160, 163, 165–167

B
background knowledge 15–17, 18, 24, 66, 222, 235, 299, 306, 308, 311–312
source domain 14, 17, 19, 24, 196, 277, 308
background metaphor 20, 116, 118, 121–122, 215, 307
backgrounding 253
see also foregrounding
Bacon, Francis 46, 113, 127–130, 133–134, 311
Baconian journey allegory 127, 129
bacterial
cells 53, 55, 58–59
colonies 51, 58–59, 61
luminescence 54–56, 63
bacteriology 54–55, 58–59, 65
balance 19, 142–143, 161, 211, 168, 211, 214, 244, 257, 301
ball rolling 247–250, 256
Bassler, B. L. 53, 56, 60, 69
Beger, A. 1–2, 4, 6–8, 10, 12, 14, 16, 20–22, 24–28, 30–32, 263–264, 268–270, 292–294, 297–298, 312–314
bilingual 141–142, 149

billiard balls 214, 301, 303
see also mechanics, force
see also motion, mechanical
biological
explanation 17, 45–46, 50, 158, 181, 186, 203, 306
processes 15, 17, 28, 30, 45, 142, 153, 175–176, 185, 194, 199
systems 28, 41, 44–45, 47, 49, 51–52, 55–56, 58–60, 68, 75
biologists 49–50, 66, 178, 187–188, 190, 192–193, 196, 201, 203, 306
biology
cellular 10, 41, 49, 52–53, 57, 68, 128, 185, 195, 252
discourse 191, 193, 195, 199, 201–203
biosciences 12, 15, 28–29, 41, 44, 47–51, 60–61, 111, 117–118, 120, 175–178, 180–181, 189–190, 194, 305–308
black people 221, 225–226, 230–231, 304
blending 6, 29, 73, 76, 78–79, 83, 94, 99–100, 106, 308
see also conceptual integration
blending theory 29, 78, 83
blends 16, 20, 23, 78, 83, 286, 300, 309–310, 313
ontological 60, 83, 100, 106
Blumenberg, H. 31, 115–117, 130, 134, 136–137, 140, 257
Bock von Wülfingen, B. 29, 118, 310, 315
body, human 16, 54, 58, 103, 178, 184, 187–188, 202
bond, physical, chemical, atomic 75, 83
boundaries 42, 44, 52, 236
Bowdle, B. & Gentner, D. 6, 212
Boyd, R. 147, 169, 176, 204, 214, 258, 264, 293
brain processes 147, 264, 278, 284, 287, 291
brain structures 191, 203
see also metaphor, processing
brain's mind 271–272, 275–278, 280, 283–284, 286–287, 290–292, 312–313
branches 178–179, 181–182, 187, 192
Brandt, C. 122, 130, 134
Brookes, D. T. 84, 98–99, 102, 108
Brown, T. L. 176, 213, 301, 305–307
Burdett, A. N. 50, 69

C
calculations 222, 224–225, 230
Cameron, L. 3, 4, 13, 19, 26, 32–33, 114–116, 134, 136, 158, 169, 176, 205, 218, 258, 306, 317
camouflage 58, 189, 193
cancer 30, 36, 58, 141, 142, 149, 165–166, 308
cancer cells 143, 147, 150–151, 153–159, 161–164
capacities, human 17, 42, 54, 57–58, 61, 75, 145, 157, 180
Career of Metaphor 6, 9–10, 16, 23, 25, 65, 71, 260, 264, 266, 268
catachresis 65, 144
categorization 6, 13, 23
causation 46, 48–51, 157–159, 161, 168, 224, 227, 233–234, 237, 239, 245, 297–298, 300–301, 305, 307
downward 48–49, 245, 248
cell death, metaphorical expressions 141–148, 150–154, 156–158, 160–164, 166–170, 307, 309
cell division 143, 160, 305
cell environment 52, 163, 166, 305
cells
body's 50, 52, 54, 141–143, 146, 148, 151, 153–159, 161, 163–164, 166, 168, 171, 289
tumorous 59, 157, 159, 161–162, 164, 166, 309
cellular biology 45, 47, 52–53, 59, 143, 166
ceteris paribus 227
chains 20, 100, 154, 166, 299, 301, 303, 305
change processes 62, 76, 224, 253, 302
chaos 76, 242, 244, 256
chaperon protein., *see* proteins
Charteris-Black, J. 20, 26–27, 32, 130, 135, 218, 258
cheating 56–57, 59, 68
chemical reactions 52, 59, 75, 151, 163, 199, 271
chemistry 12, 41, 44, 47–48, 50–51, 62, 85, 88, 176, 305–306
children 96, 99, 122, 125, 131
Chinese Room Thought Experiment 265, 271, 273–277, 280–282, 291
choice 23–24, 31, 66–67, 104–105, 125, 141, 197, 253, 257–258, 285, 293
human 168, 245, 306, 311
rational 231, 246
citizens 132, 221, 231
cladogram 182
Class-Inclusion Theory 6
clock 145, 163
cloning 29, 113, 118, 123, 125, 130
closure 246–247, 255–256
clusters of metaphors., *see* metaphor, combinations
CMT (Conceptual Metaphor Theory) 1, 4–8, 12, 22–25, 28, 41–43, 47–48, 50, 61, 64, 68, 70, 77–78, 268
central tenets of 4–5, 7–8, 19, 43, 57–58, 64–65
and Blending Theory 29
codes 17, 121–122, 191, 204, 222–223, 225, 237, 282, 304
see also metaphor, genetic code
see also metaphor in genetics, text
cognition 6, 8, 12, 69, 115, 190–192, 265, 271–272, 276–278
cognitive inference process 10–11, 14, 18, 21, 44, 48, 101, 147, 215, 223
cognitive linguistics literature 4, 76, 96, 119, 175, 185, 190–192

cognitive psychology 14, 28, 55–56, 63, 88–89, 95, 102, 188, 191–192, 194, 203
colonies 58, 116, 123, 127, 306
colours 178, 184–185, 187, 192, 201
communication
  biological 45, 53, 59, 61, 68, 126
  dimension of 9, 22–23, 157, 267–268
  expert 3, 42, 116, 176, 187, 201
  metaphoric 22, 25–28
  non-expert 26, 113, 118, 187–188, 201, 204, 212, 216, 218, 229, 303
communicative situations 22, 114, 177, 187, 204
communicators 297, 309, 315–316
community 9, 13, 27, 60, 302
comparison, analogical 11, 14, 94, 212, 256, 268, 271, 282, 315
  see also cross-domain comparison
complex chains 85, 88, 92, 101, 155, 167, 273
complexity 41, 43, 45, 48, 50–51, 246–247, 250, 252, 282, 288, 292
complexity theory 41, 48, 50–51
composite source domains 91–93
  see also complex metaphoric frames
  see also metaphor, combinations
comprehension 15, 20, 27, 158, 219, 252, 254
computationalism 222, 251, 286, 289, 304
computer program 13, 265, 271–272, 274–278, 280, 283–287, 290–292, 312–313
computer simulations 250–251, 256, 272, 302
conceptions 49, 96–99, 106, 120, 123, 125, 128, 191, 215, 223, 305
  alternative 93, 96–97, 100, 107
concepts, abstract 30, 74, 77, 81, 178, 180–181, 185, 187, 189, 195
conceptual
  blending analysis 6, 83, 99–100
  domains 4, 41, 43, 57, 60–61, 64–66, 77–78, 83, 222, 228, 246
  integration 78, 308–309
    see also blending
  mappings 5, 12, 64, 85, 93, 101, 103, 106, 187
    see also mappings, target-source
    see also metaphoric mappings
  processes 12–13, 15–16, 21, 23, 30, 61, 63, 65, 67, 302, 310
  structure 5, 7–8, 10, 12, 15–16, 21, 24, 52, 65, 226, 298
Conceptual Metaphor Theory., *see* CMT
conceptualizations 8, 12, 74, 81, 83–85, 89, 95–96, 99–100, 102–104, 106, 216, 292–293, 302–303
concordances 13
conflation/co-occurrence 13, 179, 184, 188, 195, 198
conflict, social 218–219, 231, 234, 237, 249, 251, 256, 309
connotations 120, 143–144, 159, 168
consciousness 24, 50, 127
consistency 65–66, 105, 130, 144
construals 79–80, 82–87, 89–90, 93, 96–102, 105, 107, 175, 218, 228
constructions 16, 73, 78, 99, 202
contexts 17–19, 22, 65, 74, 83–85, 87–89, 93–94, 98–102, 113–114, 116, 118–121, 149–150, 155–157, 269, 308–311
context, source domain 15, 17–18
context specific analysis 21–22, 24–25, 93–94, 96, 98, 103, 130, 132, 149, 199, 201–202, 204, 270, 311, 313
conventionality, degrees of 6, 8–9, 11, 13, 16, 21, 23, 181, 221
  see also metaphor, conventional
cooperation 56–57, 59, 68, 124, 139, 244, 306
corpora 30, 211, 218–219, 308
corpus analysis 8, 29–30, 118–121, 124–125, 141–142, 149, 167, 175–177, 218–219, 228–229, 242–243, 267–269, 298
correspondences 2, 4–5, 12, 14, 19, 23, 78, 82–83, 96–97, 276, 280–281, 304, 309
cost vs. benefit 59, 230, 253
crab species 192–193
creative examples 73, 162, 164, 193, 212, 303, 316
creatures 51, 54, 162, 309
criminology 28, 219, 221, 236, 238–239, 252
cross-domain comparison 6, 8–13, 15–16, 18–19, 25, 79, 81, 104–107, 189–190, 192, 220, 276, 278, 280, 300–301
cross domain mapping 6, 11, 27, 65–66, 114, 182, 194, 198, 268
CTM (computational theory of mind) 263
cueing, simultaneous 198
cultural experience 49, 117, 156, 234–235, 298, 311, 315
culture 17, 45, 50, 55, 114, 130, 156, 232, 311

D

Darwin, C. 3, 32, 46–47, 50, 69, 205
data, quantitative 42, 150, 152, 221–222, 225–227, 229
dataset analysis 62, 219–220, 222, 224, 229, 250, 253–255, 257, 304
death 125, 142–148, 150–152, 154–156, 159, 161–163, 166–168, 221, 300, 308–310

defenses 58, 64, 151–154, 163–164, 189, 199
Deignan, A. 7, 13, 32, 36, 270, 282, 293, 294
deliberate metaphors 24–26, 31, 67, 119, 125, 263, 266–269, 270, 283–285, 287, 290, 291, 293, 312
  see also metaphor, deliberate
deliberation, speaker's 24–26
Dennett, D. C. 50, 263, 265–270, 280–285, 288–289, 291–292, 294–295
  see also Hofstadter, D. R. & Dennett, D. C.
dictionaries 56, 116, 118, 149, 215, 229
directionality 15–16, 43, 50, 104, 185, 191, 234–236, 239, 243, 249, 251, 254–255
discourse
  actual 7, 24, 42, 64, 267
  general 26–27, 42, 106, 118, 132, 266, 268, 270, 302, 315
  pedagogical 76, 85, 88, 93, 268
  specialist 2–3, 13, 31, 116, 121, 268–270, 298
discourse analysis 8, 23, 116, 119, 194, 266, 269–270
discourse contexts 21, 267, 269–270
discourse events 7–8, 26, 266–270, 284–285, 313
discovery, scientific 9, 53, 123, 127–128, 155, 165, 193, 308, 311
diseases 27, 54, 59, 124–125, 131, 143, 156
disorder 86–87, 104–105, 232
DNA 121, 130, 160, 163, 165–166, 183, 310–311
documentaries 30, 176, 192–193, 195–197, 199–202, 204
domains
  concrete source 16, 20, 94, 100, 211, 252, 255, 301–302, 304, 310, 312
  conventional source 4–5, 10, 12, 16–17, 21, 24–25, 102, 105, 114, 305–306, 308–309
  see also metaphor, conventional
  scientific 74, 85, 244, 312
  socio-cultural 15–17, 41, 55, 68, 310
  source and target 13, 79, 81, 104–107, 198
Dreyfus, B. W. 83, 108
dynamical systems 26, 211, 219, 239–246, 249–252, 255–256
dynamic image 178, 187, 193–194

E

ecological fallacy 225–226
ecology 27, 190, 204, 244
economics 16, 48, 62, 230, 234–235, 242
education 3, 18, 31, 63, 66, 93, 113–114, 235, 288, 293
efficacy, communicative 22, 24, 195, 204, 269
elaborations 52, 80, 85–86, 168, 281, 292
electricity metaphorically understood as a fluid 4–6, 233
electrons 67, 76, 81, 184, 213–218, 251, 301
elements, aligning source domain 15, 203, 240, 307
  see also aligning source and target features
El Mundo 141, 149, 152–153, 158, 161, 167, 172
El País 149, 152–153, 159–160, 164–166, 171
elucidate 13, 16, 26, 148, 153, 155, 158, 167–168, 218
embodied simulation 17, 20, 256
embodiment 15–16, 41, 67, 74, 184, 188, 190, 215, 301–302, 304–305, 312, 315–316
  see also experience, bodily
embryo, selected 121, 125, 310
emergence 7, 41, 45, 47–48, 60–61, 68, 83, 241, 245, 247, 255
  supervenience 41, 61
  theory 47–48
emotions 22, 42–43, 198, 202, 243–246, 308, 313
empirical results 26, 88, 167, 175, 183, 186
encounters, conflictual 201, 219–220, 225, 230, 234
enemies 58, 189–190
energetic state 80–81, 86, 90, 97, 105, 303
energy (forms of) as containers., *see* metaphor, container
energy
  amount of 82
  conservation of 75, 81–82, 84, 86, 93, 103
  construals of 29, 74, 76, 79–80, 83, 93, 96–97, 100–101, 103, 114
  nature of 51, 56, 79–81, 83–84, 87, 97, 215–216, 299, 305
  as location 75–76, 79, 81–84, 86, 90, 98, 102–103, 303
  states 75–76, 80–83, 87, 90, 95, 103–104, 303
English subcorpus 149–153, 155, 161, 167–168, 170
entertainment 30, 191, 195, 197, 203–204, 314
entrenchment, degree of 27, 177, 181, 201, 242
entropy change 87, 89–90, 92, 95–96, 104
environments 52–55, 59–60, 96, 102–103, 167, 187, 198, 234, 269, 301
enzymes 146, 153–154, 160, 166
epistemological confusion 19, 21, 106–107, 116–117, 132, 146, 250, 263, 286–288, 292, 299, 302–303, 306–310, 312–313, 315–316
equations 19, 79, 215, 250, 277, 304
equilibrium 85, 91, 240, 244–249, 255–256
errors 98, 100, 106, 165, 250
  see also epistemological confusion
Etkina, E. 98–99, 108

eugenics conceptualization 178–181, 203
evaluations 29, 124, 224, 315
Evans, V. 101, 108, 185, 205
everyday language 42, 44, 65, 77, 80, 96–97, 99–100, 107, 114, 116–118, 228, 232, 238
evidence of metaphor 5, 7, 11–14, 63, 93–96, 98, 163–164, 178, 187–188, 194–195, 199, 203–204, 229–231, 237, 271–272
evolution 3, 15, 33, 46–47, 49–50, 53, 68–70, 123–124, 128–130, 180–181
experience
  bodily 15–16, 19, 184, 187, 214, 222, 256, 300, 305, 311–312
  sensorimotor 16–17, 42–43, 176, 178–181, 184, 187, 194, 198, 220, 223, 225, 310, 312
experiential gestalts 15–16, 19, 42–45, 51, 60–61, 63, 65, 68, 305–306, 312, 315
experimental studies 5–7, 14, 52, 57, 122, 130, 251, 256, 293, 302, 307
experimentation 10, 42, 46, 53, 191, 204, 216, 246
experiments 5–6, 29, 62, 65, 68, 86, 246, 250, 256, 293, 301–302
expert authors 101, 113–114, 118, 188
expertise, acquisition of 74, 88, 93–95, 100–101
experts 113, 116–119, 142, 144–145, 147, 165, 167, 191, 193, 196–197, 291, 293, 297
explanations, scientific 23, 41–42, 61–64, 69, 257, 289, 297, 299, 312–313
explanatory models and metaphors 29, 53, 56, 66–68, 99, 193, 217, 300–301
exposure to metaphoric discourse 27, 98–99, 101, 106–107, 141

F

Fauconnier & Turner 6, 20, 29, 33, 37, 78, 83, 108, 110, 308, 317–318
feedback loops 246, 250–251, 256
Feynman's metaphorical construal of energy 79–80, 108
fiction 117, 119, 129, 132
  see also epistemological confusion
field theory 219, 232–233, 235–240, 244, 250, 254–256, 301
figurative
  description 21, 183, 193, 201, 212
  thought 175–176
films 198, 201
  see also video clips
fitness landscape 50, 67
forces 125, 161, 164, 220–221, 224–225, 227–228, 230–237, 240, 242, 244–245, 249–250, 254–255, 301–302
  see also mechanics, force
  see also motion, mechanical
Forceville, C. 20, 37, 175, 177, 195, 198–199, 204–205, 207, 309, 317
foregrounding 23, 181, 253
frames, metaphoric 16, 27, 147, 223, 225, 306, 310–312
Fryer, R. G. 227–229, 231, 258, 261
function
  cognitive 12, 101, 192, 206, 254, 272, 275
  communications 1, 23–25, 41, 64, 81, 312, 315–316
  discourse 7–8, 21–22, 28, 30
  language 8, 23
  pedagogical 117, 121, 303
  perspective-changing 24, 115, 119, 154, 168, 282, 284–285, 292
  textual 115, 129

G

generative qualities 27, 256, 305, 308, 316
  see also hypotheses, generating
genetic
  code metaphor., *see* metaphor, genetic code
  technologies 29, 48, 117–118, 123–127
    reproductive 29, 113–114, 118–121, 123–125, 129, 131–132, 139, 310–311
genres 13, 24, 29–30, 145, 150, 156, 161, 164, 167, 266, 269–270
Gentner, D. 6, 9, 13–15, 19, 32–33, 73, 108–109, 116, 135, 258, 261, 315, 317
gestalts 15–16, 181, 305, 312, 315
  see also experiential gestalts
gestures 19, 79, 83, 175–176
Gibbs, R. W. 4–5, 14, 21–22, 26, 32–34, 36–37, 64, 67, 70, 74, 136, 205–206, 294–295
Gibbs, R. W. & Colston, H. L. 11, 14, 176
Giles, T. D. 3, 10, 33, 116, 135, 213, 217, 259
Giora, R. 13, 15, 18, 33
Goatly, A. 115, 117, 119, 132, 135, 213, 259
Grady, J. E. 20, 34, 37, 178–180, 184, 189, 199, 205, 215, 259
grammar 98, 122, 138
  see also metaphor, genetic code
  see also metaphor in genetics, text
gravity 233, 248, 249, 250, 302
  see also metaphor, force
grounded metaphor., *see* metaphor, grounded
group averages 225, 237, 306
groupings of metaphors 307
  see also metaphor, combinations
groups, human social 225–227, 229, 246, 252, 306
guide scientific exploration 10, 13, 102, 105–106, 211–212, 214, 218–219, 222, 224, 251, 254–255, 257, 305, 307

see also hypotheses, generating

H
Haglund, J. 74, 85, 94, 99, 107–109
Halliday, M. A. K. 115, 132, 135
Hallyn, F. 2, 34–35, 74, 109, 214, 259
Hamer, D. 125–126, 133, 138–139
harvestman 197, 199–202
Hastings, J. W. 54–55, 71
heat and entropy 74, 76, 79, 83, 93, 100–102, 106–107
hedges 21, 158, 192, 228
helper metaphors 216, 228, 238, 243, 247–248, 250–251, 253, 256–257
Herrmann, B. J. 32, 34, 36–37, 114–115, 117, 135, 260, 267, 295, 318
high-low metaphors 242
see also scale, verticle
high-pitched sound 197–199
high quality newspaper 29–30
Hofstadter, D. R. & Dennett, D. C. 263, 265–270, 280–285, 288–289, 291–292, 294–295
Holyoak, K. J. & Stamenković, D. 4, 14, 18
human biotechnology 54, 58, 113, 120, 131–132
hypotheses 63–64, 67–68, 176–177, 190–192, 194, 211, 214, 216, 218, 237, 239, 301, 306
generating 9, 11, 23, 28–30, 42, 60–61, 63, 65, 68, 306, 316
hypothesis formation 42, 253, 301

I
ideational 115, 119, 214, 311
see also cognition
idiosyncratic 177, 193, 199, 201, 204, 231, 313
see also metaphor, novel
imagery 122–123, 193, 203–204
images, useful 103, 105, 141, 144, 147, 150–152, 154, 161–162, 164, 166–168, 178, 187, 192–198, 202, 204–205
image schema 16, 44, 77, 81–82, 89, 94, 100, 102–103, 176, 191, 234
implicit metaphors 74, 99
see also metaphor, conventional
indirect metaphors 21, 25, 27
inference structure 20, 23, 73–74, 77, 80, 177, 181, 189–190, 203, 214, 303, 306
inference to the best explanation 41, 63
inferences 5, 23, 56, 62–63, 82, 105, 211, 220, 306, 315–316
abductive 41, 61–63, 68–69
inductive 62–63, 165
inhibitory control 14
see also metaphor, processing
input output 83, 90, 272, 277–279, 289, 313
see also conceptions, mechanical
see also motion, mechanical
see also mechanics, force
instantiations 43, 67, 278–279, 286
instruction 73–74, 76, 100, 102–103, 105, 107, 128
instructional materials 23, 100–103, 106, 158, 197, 201, 257, 303, 315
integration 247, 308, 310
see also blending, conceptual integration
intentions 120, 244, 313
see also metaphor, deliberate
interest, see target domain elements
interpretations, alternative metaphoric 61, 78–79, 99, 105–107, 129, 131, 201–202, 223–224, 228, 231, 310, 312, 314

J
Jäkel, O. 7, 31, 34, 115, 129–130, 136
jellyfish 9, 54
Jeppsson, F. 74, 85, 88, 91–92, 94–95, 99, 102, 107–109
Johnson, M. 3–5, 7, 9, 34–35, 42–44, 64, 70, 77, 109, 114–115, 136, 180, 205, 258–259, 264
journalists 2, 28, 117, 119, 154–155, 165, 167–168, 217, 221, 231, 257
journey, see metaphor, journey

K
Katzorke, T. 125, 133, 137, 139
Kerr, J. F. R. 143, 169
kinaesthetics 188
knowledge, scientific 28, 177, 183, 202, 298, 314–315
knowledge communication 264, 267
knowledge domains 3, 18, 21, 23, 29, 61, 63, 185, 191, 194, 226
Knudsen, S. 9–10, 15, 34, 199, 212, 214–215, 217, 259, 264, 294, 298, 307, 316–317
Koller, V. 20, 34, 36, 115, 120, 136, 140, 189, 205
Kövecses, Z. 16, 18–19, 34, 41–42, 71, 77, 220, 223, 259, 305–306, 308, 313, 317
Kroemer, G. 144, 148, 151, 169

L
Lakoff, G. 4–5, 35, 42–44, 70, 77, 109, 115, 136, 178, 180, 205, 259–260, 264, 300–301, 317
Lakoff, G. & Johnson, M. 4, 12, 16, 20, 41–42, 46, 50, 115, 179, 181, 185, 188–189, 224
Lakoff, G. & Turner, M. 15, 20, 214
language
literal 21–22, 166, 215, 302
see also literal meaning, literal truth
metaphorical 8–10, 18, 22, 32–33, 51–52, 77, 92, 97, 124, 144, 153
ordinary 5, 7–8, 12, 23, 96, 107, 116
science 42, 59, 61, 68, 74, 76, 98, 104, 107, 177

see also scientific discourse
layers 14, 30, 59, 88, 236, 240, 254
laypeople 113, 175, 178, 191, 195, 200–201, 203–204, 213, 232
learning and instruction 73–77, 79, 81, 83, 85, 87, 89, 91, 93, 95, 97–101, 103, 105–107
lecture, academic 83, 263–267, 269–271, 273, 275, 277, 279, 281, 283, 285, 287–293, 298
letters 121, 128, 131, 138, 183
  see also metaphor, genetic code
  see also metaphor in genetics, text
levels
  macroscopic 16, 85, 95, 240, 301, 306
  microscopic 48, 68, 85, 87, 95–96, 214, 252
life cycles 47, 123, 138, 155, 185–186, 263
light 52, 54, 63, 67, 157, 162, 168, 197, 200–202, 215, 221
light music 197, 201
  pace 197, 199, 201
Linell, P. 266, 268–270, 294
lines/arrows 184, 300
linguistic
  evidence 6–7, 29, 44, 64, 78, 83, 190, 263, 267–268, 293, 307
  form 7, 10–13, 76–77, 87, 89, 92, 116–117, 144–148, 150–151, 153–155, 158, 162–165, 196, 199
  metaphors 6–7, 151–152, 155, 197–199, 201, 267, 269–270, 298, 310
links 76, 93, 119, 122, 145, 199, 227
listener 66–67, 78, 115, 132
literal
  meaning 6, 9–10, 20, 23, 96–97, 115, 212–213, 215, 218, 316
  truth 263, 265, 276, 280, 284–285, 290–291, 313
literary theme 126, 130
Littlemore, J. & Semino, E. 7, 13
living organisms 44, 46–47, 52, 142, 150, 182, 193
Lockshin, R. A., & Zakeri, Z. 143–145
logic 16, 22, 49, 62, 129, 220, 233, 283
loop 63, 250
  see also feedback loops
loss of substance 76, 86–87, 89, 143, 244
love 12, 19, 43–44, 51, 77, 122, 180
  see also journey metaphor
lysosomes 146, 166

M

machines 16, 66–67, 87, 90–92, 124, 154, 280, 288, 312–313
  see also conceptions, mechanical
  see also motion, mechanical
  see also mechanics, force
macro level 17, 43, 48, 223, 240–243, 245, 248, 255–257, 302, 305–306, 311–312
  explanations 85, 236, 239, 242, 245–246, 312
  outcomes 45, 239, 241, 252, 255, 257
Majno, G. & Joris, I. 145–146, 157
manipulation 119, 125–126, 193, 222, 224, 228, 253
  educative 125, 129, 276
  physical 90–92, 125–126, 229
  statistical 227, 230
mappings, target-source 3, 5–6, 12–13, 15, 78, 80–81, 100, 104–107, 194, 197, 201–202, 216, 274, 288–289, 292–293
Maran, T. 191, 204, 206
Martin, J. L. 206, 224, 233–235, 260–261
mass 66, 74, 82, 218, 233
mathematics 75–76, 88–89, 130, 176, 184, 215, 223, 301, 304–305
matrix 59, 233, 240, 254, 269
mechanics, force 77, 81, 86, 184–185, 232–233, 235, 245, 249, 253, 300–301, 303
mechanism 50, 55, 58, 73, 143, 147, 153–155, 160–161, 163, 196, 233
  cognitive 6, 23, 73, 191
media 29–30, 113–114, 117–119, 132, 221, 226
Melino, G. 144, 146, 148, 151, 156, 170
memory 14, 20, 63, 115, 147, 190–191, 264
mental spaces 65, 78, 308
messenger 53, 55
meta-metaphors 61
  see also metaphor, overarching
Metaphor Identification Procedure, *see* MIP
metaphor in genetics, text 116, 129, 131
  see also metaphor, genetic code
metaphor métier, scientific 212–215, 218–219, 227, 232, 250
metaphor-savvy 310, 315
metaphor
  abstract 19–20, 50, 94, 105, 167, 178, 181, 189, 240, 297, 304
  across genres 142, 144, 146, 148, 167, 215, 228
  activation 26
    see also metaphor, deliberate
  algae 185, 190, 192–195
  analysis 3, 30–31, 96–97, 100, 102–103, 113, 115, 119, 267, 270
  archerfish 195–197, 199, 201, 204
  arrows 184–187, 196, 200
  assigning numbers 221, 223–224, 253
  attractor 247–251, 256
  basin 248–249
  biology 51, 175–177, 307, 310
  Book of Nature 121, 130
  botany 119, 121

central 212, 215, 217, 219, 251–252, 255, 280, 285, 291, 301, 304
circle 118, 147, 185–186
colony 48, 51, 55, 58–59, 117, 120, 123, 126–129, 131, 306
combinations 15–16, 18–21, 23–24, 27, 74, 83, 85, 88–91, 93, 100–101, 105–107, 118, 120, 158, 168, 297–298, 301, 307, 309–311, 315–316
complex 31, 44, 265, 270, 292
computer 147, 265–267, 270, 273–274, 278, 280, 288–291, 312
conceptualization 14–15, 22, 30, 45, 77, 83, 85, 176, 187, 194, 218
container 16, 20, 47, 52, 75, 77, 80–82, 87, 90–91, 97, 303, 305
control 188, 190, 194
conventional 6, 11–15, 18, 23, 44, 64–65, 113, 115–116, 121–122, 129–130, 199, 201–202, 238, 301, 310–311
correlation 48, 87, 179, 184, 188–189, 223, 227–228
danger 120, 122–123, 127, 131, 188, 307, 311
dataset 219, 221, 224, 226–229, 231–235, 237, 239, 251, 253–254, 304
deliberate 24, 31, 66–67, 119–120, 125, 216, 263, 266–270, 283–285, 287, 290–291, 293
direct 13, 20, 25, 269
dramaturgical 197–198, 201–202, 238
effectiveness 24, 42, 61, 64, 99, 162, 175, 183, 201, 268, 315
energy, substance 82, 103–104
Event Structure Metaphor 77, 83, 85–87, 104–105, 300–301, 303
explanatory 41, 68, 300
extensions 42, 216, 227–228, 291, 316
factory 45, 52, 64, 66–67, 69
field 233, 237, 240, 255, 301
field theory 231, 233–234, 236–237, 239, 251, 255
fluid 5
force 233, 248–250, 302
fruit 50, 121, 129, 137, 310–311
game 16, 123, 238
genetic code 9–10, 45, 98, 121–122, 128, 131, 143, 158, 163, 183
see also metaphor in genetics, text.
grounded 81, 184, 187, 193, 204, 223, 297, 302, 316
heat, substance 93–94, 98–100, 102, 105
high-low, *see* scale, verticle
homeostasis 142–143, 244
incorrect 107, 292
see also epistemological confusion
journey 15–16, 31, 41, 44, 85–86, 92, 120–121, 123–124, 126–130, 132, 180, 250–251, 290
landscape 248–249
levels 246, 255
lexical, verbal 242, 149–150, 193, 197, 199, 201–202, 204, 211, 216, 219–220244
see also linguistic metaphors
Location Event Structure metaphor 80, 83, 85, 87, 105
mechanistic 144, 148, 153, 155, 158, 168, 233, 235, 301, 303, 306
monomodal 177–178, 197
multi-modal 30, 175–179, 181, 183, 185, 187, 189–191, 193–195, 197, 199–205, 309–310
nature 43, 45–47, 49–50, 120, 122–124, 126–131, 175, 178, 184, 186, 200, 202, 270–271, 291–292, 308–309
necessary 116, 120–121, 311
non-resemblance 175, 177, 187, 189, 201, 203–204
nonlinguistic 176, 300
novel 6, 8–12, 14–15, 20, 23, 73, 193, 196–197, 199, 201, 267–269, 272, 277, 280, 291–292
Object Event Structure metaphor 77, 80, 85–86, 103
orbits 214–217, 244, 251, 301
orientational 48, 300
overarching 20, 27–28, 44, 60–61, 68, 185, 199
pedagogical 52, 67, 76, 102, 106, 187, 191, 194–195, 201–202, 306, 309
pioneer 123, 138
primary 7, 20, 63, 67–68, 179–180, 184, 187–190, 194, 198–199, 204, 215
processing 6–7, 14, 17–18, 20, 23, 26, 191, 203
propaganda 24, 178, 297, 308, 310–311, 314, 316
rational choice 230, 253
recontextualization 21, 167, 240, 266–270, 280–293, 312
research 2, 7, 13, 15–16, 23, 177, 183, 218, 297
reuse 265–267, 269–270, 313
scholars 2, 4–5, 15–16, 20, 22, 27, 176, 297, 304, 307, 314–316
scientific 18–20, 22, 28–29, 50, 75, 82, 93, 96, 64–65, 68, 211–213, 216, 219, 298–299, 303, 305, 309–310, 312–313, 315
single 10, 14, 61, 74, 282
social 15–16, 18, 28–29, 41–45, 51, 53, 55–57, 59–61, 67–69, 115, 219–220, 233–238, 25455, 301–302, 305–309, 315–316
solar system 214–215, 217, 301
source domains 13, 15–16, 18–20, 214–215, 220, 298, 300, 304, 306–307, 313
space 22, 78, 99, 123–124, 126, 131, 180, 184–185, 233, 250, 300–301
spider 186, 188–194, 203

studies 4, 8, 28, 64, 191, 299, 313
suicide 141–142, 145–148, 150–151, 153–159, 161, 165, 167–168, 308
technical 10, 23, 26, 116, 119, 145, 148, 150, 152, 307, 316
terrain 235, 243, 249
theory-constitutive 24, 147, 176–177, 193, 215, 264, 290, 297, 301, 312
theory 109, 114, 118, 189, 299, 302
throwing dice 122, 138
thunderstorm of the nerves 122, 138
time passing 242
translation, genetic 9–10, 119, 127, 130–131
tree, eugenics 187, 203
underlying 6–7, 12, 94, 184–185, 241, 253, 264
valley 243, 248–250
violence 163–164, 201
visual 3, 30, 175–176, 178, 180–181, 183–185, 187, 189–191, 193–197, 200–201
vocation 211–213, 218–219, 232, 252
war 43, 58, 154, 164, 199, 201–202, 309–310
wave 192, 215–217
weapon 145, 151–152, 163–164, 196–197, 199, 201, 204, 310
metaphoric 9–10, 26, 45–46, 96–97, 101, 144, 148–150, 152, 212, 248, 250, 265, 280
analogies 263, 265, 270–271, 276, 278–282, 291–293
construal 79, 81, 83–84, 86, 90, 96, 98, 101, 107
expressions 9, 12, 43, 77, 79, 93–95, 106–107, 141–142, 148, 150, 152–155, 158, 164, 167, 269–270
field 120–121, 124, 126–127, 129, 131
mappings 13, 43, 74, 76–77, 81, 83–85, 87–88, 90, 93, 95–96, 223, 225–226, 255–257
source domain-to-target domain mapping 12, 14, 19, 22, 308
meaning 11, 13, 17, 22, 26, 115, 121, 137, 175–177, 201–202
patterns 43, 57, 77, 119, 184, 189, 195, 204, 243
representations 61, 120, 122, 178, 184–185, 187, 192, 195, 200, 220, 225
structure 115, 188, 197, 204, 240, 256, 301, 304, 312
thought 184, 187, 191, 193, 196, 202, 211, 215
words 18, 119, 218, 228
metaphoricity 9, 11, 22, 26, 151, 187–188, 215, 217, 229, 271, 316
methodology 8, 23, 119, 126, 218–220, 231, 256, 267
scientific 28, 62–63, 127, 258, 314
in metaphor study 12, 20, 22–23, 28, 212, 298
metonymy 20, 180, 185, 196, 317
microcosmic, level 43, 223, 241–243, 245, 248, 252, 255–257, 300–302, 305
microorganisms 47, 54, 306
microstates 87, 95, 105
mind, foremost in our 13, 17, 24
see also saliency
mind, human 31
MIP (Metaphor Identification Procedure) 12–13, 30, 36–37, 149, 170, 198, 218, 253, 267–268, 295, 318
misconceptions 19, 146, 299, 302–303, 306, 312–313, 315
see also epistemological confusion
misrepresentation 263, 286, 287, 288, 290, 292
see also epistemological confusion
models 55–56, 61, 63, 68, 99, 230–231, 299, 304
computational 19, 215, 289, 302–304
explanatory 3, 49, 59, 63, 181–182, 189, 213, 223, 299, 301–302, 304
modes 133, 146, 177–178, 184, 194–198
communicative 68, 92, 175–176, 194, 196, 198, 201–202
modifications of metaphors 213, 252–253, 266–267, 269, 291–292
molecular biology 41, 43, 45, 47, 49, 51, 53, 55–57, 59, 61, 63, 65, 67–69
molecules 43, 45, 49–50, 52–53, 55, 57, 60, 63, 87, 153–157, 160–161
motion 3, 75, 79, 84, 180, 184–185, 213–217, 233, 301
mechanical 66, 193, 224, 252, 300, 302–303, 310
motivation 1, 121, 144, 154, 156, 168
movement 15–16, 52, 77, 80–82, 85–87, 90, 92, 94, 184–185, 188, 190, 192–193, 224, 242–244, 300–301
nonlinear 240, 243–245, 247, 250, 253, 255–256
into/out 16, 86–87, 202, 214, 217
Müller, C. 26, 35, 205
murder 147, 158, 168
music 175, 195, 198, 201–202, 282

N

narratives 20, 23, 85, 88, 91, 94, 128, 132, 193–197, 199, 201–202
natural sciences 28, 30, 113–114, 119–121, 127–128, 176, 181, 186, 195, 200, 204
natural selection 46–47, 50, 69
NCCD (Nomenclature Committee on Cell Death) 144, 148
Nealson, K. 54–55, 63, 71
Nerlich, B. 2, 35, 131, 140, 170, 313, 317
network semantics 13, 19, 114, 176, 193, 247

neural network 48, 289, 298, 304, 312
Newtonian inferences 214–216, 235, 252, 301
non-deliberate metaphors 24–26, 268–269
non-linearity 239, 241, 243, 247, 256
non-metaphorical 10, 199, 215–217, 316
  see also dead metaphor, closed metaphor
non-resemblance metaphor 186, 189
nonverbal metaphor, *see* metaphors, multi-modal
Nova Atlantis 128, 130
nuclei 53, 143, 147–148, 151, 160, 166, 213–214, 216, 301
numeracy 222–223, 253
Núñez, R. E. 3, 35, 136, 176, 206, 222, 259

O

observational studies 28, 30, 41, 44, 63–65, 176–177, 211, 214, 216–218, 222, 224, 229, 231, 255–256
online processing 6, 11, 21, 27, 196, 264
ontological inconsistency 102
  see also blends, ontological
ontologies 81, 102, 130, 214
Origin of Species 46–47
Ortony, A. 2, 11, 22, 35–37, 74, 109–110, 135, 137, 140, 204–205, 258–259, 293, 317

P

partial mapping 275, 288
  see also mappings, target-source
  see also metaphoric mappings
part/whole 86
path-goal schema 44, 123, 126, 129, 131, 138, 185
path metaphor 15, 31, 41, 85–86, 92, 123–124, 126–129, 180, 250, 290, 300
  see also metaphor, journey
PCD., *see* programmed cell death
pedagogy 211, 217, 299, 314
Peirce, C. S. 62–63, 68
Pelengaris, S. & Khan, M. 143, 154, 167
personification 154–155, 159, 161, 164, 316
perspective 29, 31, 64–65, 74, 76–77, 79, 100–101, 115, 119, 288, 291, 293, 299–300
  change in 20–21, 24, 76–77, 96, 188, 192, 194, 214, 216, 237, 239, 268, 303, 306–307, 309
persuasion 67, 158, 263, 266, 291, 299, 311, 316
phenomena, scientific 18, 21, 23, 300, 308
philosophers of science 28, 46, 62, 176, 299
philosophy 62, 64, 77, 113, 127, 263–264, 266–267, 299
Philosophy of Mind 264–266, 285, 291
phylum target domain 181, 197
physical source domain 14, 16, 20, 124, 128, 182, 184, 189–191, 193, 217, 254–255, 301–302, 304
physical vertical dimension metaphor, *see* scale, verticle
physics target domain 15, 29, 31, 44, 47–48, 51, 85, 88, 101, 103–104, 211–213, 252, 254–255, 301–306
physiology 53, 126, 139, 180, 198
picture corpus 73, 79, 129, 175–176, 178–180, 183–186, 215, 233, 237, 254, 289
pie charts 81
  see also representations, modes of
Pisa armata, crab species 192–193, 203
pitch, high 198
Planck, Max 301–302
plants 16, 46, 53, 56–57, 121, 150, 154, 185, 310–311
plaque, dental 51, 59–60
poetry 15, 18
  see also artistic domains
popularization 1–2, 29–30, 113, 121–122, 145, 195, 202–203, 211, 297, 299, 314–315
  press 141–143, 145, 147, 149, 151, 153, 155, 157, 159, 161, 163, 165, 167, 171
positions, sub-mappings of 114, 117, 181–182, 185, 188–189, 214–215, 230, 233–236, 239, 244, 254–255
possessions/substances 77, 80, 86, 90–91, 97, 103, 253, 315
posture 188, 191, 203
power 16, 56, 179, 188, 226, 234–236, 239, 254–255, 302, 311
Pragglejaz Group 13, 30, 36, 149, 170, 298, 318
pragmatic theory of truth 62
predators 56, 188–189, 192–193, 203, 244
predictions 63, 68, 147, 234, 251, 254, 256, 297, 299, 302–306, 312, 314, 316
presentation 7, 81, 83, 93, 181, 195, 219, 257, 298
probability 87, 216, 225, 254, 278, 284
problem-solving 88–94, 100, 103, 106, 315
process, unfolding, spontaneous 9, 47, 75, 84, 86, 233, 242
processes
  conceptualization 14–15, 19, 306
  dynamic 48, 100, 241, 254, 304, 310
  mental 14, 181, 275–276, 279, 283
  microscopic 47, 51–52, 61, 87, 124, 141, 167
productivity 201, 203
programmed cell death (PCD) 116, 144–146, 148, 151–152, 157, 159, 161, 163–165, 167, 308
promotional value 30–31, 194–197, 199–202, 204, 299, 314, 316
pronouns 90, 92, 94, 101

proteins 9, 17, 53, 58, 65, 67, 153, 157, 166
prototypical 13, 176, 225, 274
psycholinguistic studies 5, 14, 27
psychological dynamics 31, 48, 236–237, 240–246, 248, 250, 254–255, 301, 304, 309
public goods 56–57, 59
  see also social behavior

Q
quantification 3, 75, 81, 89, 223–224
quantum theory 130, 215, 302, 304
quorum sensing 41, 54–56, 58–61, 63–65, 68, 306–307

R
racial differences 78, 220–221, 224–231, 234, 253
rational actor models 230, 246
rational choice theory 221, 230
readings 130, 285, 288, 292–294
realizations 8, 11, 13, 30, 194, 196, 264
real time processing 6, 11, 27, 196, 264
  see also online processing
reasoning
  audience's 10, 23, 95, 100, 107, 265, 292, 302
  contexts 99–102
  metaphoric 30, 61–62, 68–69, 195, 203, 243, 245, 263, 276, 292
  qualitative 90–93, 100–101, 302, 304
  scientific 7, 27–28, 68–69, 73–74, 85, 88, 96–97, 106, 224–225, 251–252, 254, 298–299, 303, 305–307, 316
recontextualization of metaphors 263, 267, 269
  see also metaphor recontextualization
relatedness 19, 89, 222, 233, 251–252, 254–255, 300, 304
Relevance Theory 6, 32
reliability 61, 63
repetitions 94, 158, 198, 266–267, 289
representation
  conceptual 77, 81, 83, 96, 184, 233
  incorrect 30, 287, 289, 292
  modes of 79, 81, 83, 92, 94, 178, 181, 183–184, 195–196, 200, 204
reproductive process 28–29, 57, 117–118, 121–123, 125–126, 131, 310–311
research 15–16, 60–61, 73–75, 99, 101–102, 175–177, 204–205, 217, 220, 222, 255
  scientific 3, 7–8, 10, 12, 31, 176, 181–182, 188, 227, 237, 293
resemblance metaphor 14, 144, 177–178, 182, 189, 194, 201, 203–204
resources 17, 57, 80–81, 97, 103, 107, 123, 204, 213, 233, 237–238
  conceptual 97, 103, 130
  pictorial 103, 185, 187
responses, bodily 44, 60, 149, 161, 184, 195, 201, 256
rhizobia 57
rhythm 198
richness 87, 116–117
RNA 9, 45
roles, central 103, 122, 145, 148, 175, 184, 204, 211, 271
roots 57, 178–181, 187, 203, 241

S
safety 153–155, 164, 249
saliency 13–14, 17, 21, 23–24, 194, 197, 223, 234, 298, 310, 316
sarcoma 165
scaffolding 102, 126, 216
scale, verticle 19, 45, 81, 83
scenarios 20, 68, 116–117, 120–121, 126, 128, 131, 272–276, 281, 291, 300
Schank, R., & Abelson, R. 271–274, 276–277, 294
schema 103, 181, 187, 215, 253
Scherr, R. 81–82, 103, 108, 110
Schmitt, R. 113, 115, 119, 137
Schrödinger, E. 9, 122, 130, 140, 215–216
science
  pedagogy 1–3, 18, 24, 28–29, 31, 41, 61, 64–68, 96, 102–103, 107–109, 176, 256–257, 314–315
  popularization 1–3, 24, 26, 29–31, 113, 168, 256
  writers 22, 74, 84, 101, 104, 216–217, 299, 302–303, 305–307, 309–312, 314–315
scientific
  communication 2–3, 5, 7–8, 10–11, 15–19, 21, 23–24, 26, 28, 144–145, 147–148, 297, 299, 310, 314
  concepts 7–8, 10, 12, 24, 29, 31, 73–74, 97, 99–100, 102, 105–107, 314–315
  discourse 3–4, 30, 64, 67, 75, 79–81, 84, 93, 99–107, 146–147, 298–300, 307–309, 314–315
    see also language of science
  findings 61, 74, 88, 93, 100–101, 185, 203, 251, 257
Searle, J. R. 263–293
  arguments 271, 276–278, 280, 283–284, 286, 290–292
  article 265–266, 270–271, 273–274, 280–281, 289
  Chinese Room Thought Experiment 276, 280
  concept 265, 270, 282, 285–286
  constructs 274, 276
  goal 265, 272, 284, 287
  metaphors 265–266, 269, 274, 280–284, 287–290, 292
self-destruction 145–146, 150–151, 153, 157, 159–160, 162–163, 166
self-organization 27, 48, 50–51, 180, 241, 245–247, 250, 256
sell-by date 152, 158, 163
semi-autonomous fields 236, 239, 254
Semino, E. 7, 32, 36–37, 114–116, 137, 140, 148, 156,

158, 170, 214–215, 218, 270, 282, 293–294
semiotic function 28, 41, 45, 60–61, 68, 192
senescencia 165
sensorimotor 75, 77, 178, 181
sensory-motor experience 7, 300, 303
sequences 192, 196, 198, 232, 301, 303
  see also narratives
  temporal 107, 185, 193, 198–199, 202, 238, 248, 301
sharks 183–185
signalling 21, 45, 53, 55, 60, 63, 146, 153, 157, 163, 306–307
similes 11–14, 23, 25, 28, 298
similes and analogies 8, 11–12
single-cell organisms 46, 51, 54, 306
situational factors 222, 225, 232, 242
Smith, T. H. 211–212, 297–298
social
  behavior 51, 55–56, 222–223, 227, 230–232, 236, 239–241, 243–244, 247–248, 251–253, 255–256
  field theory 232–233, 236–240, 250, 254–256, 301
  interaction 211, 220, 228, 232–233, 243–244, 301
  phenomena 17, 218–219, 222, 228, 233, 253, 306
  process 30, 218, 220–222, 224, 226–227, 234–237, 240, 251, 253–255, 301, 304–305
  science 28, 30, 218–222, 224, 231, 242–245, 251–254, 256
  science research 211–212, 219, 222, 245
  scientists 219–223, 225, 228–229, 232–233, 240, 242, 251, 254–256, 304–305
society 124, 127–129, 131, 133, 156, 257
solar system 213, 251
sound 9, 14, 103, 142, 195, 197–199, 201–202, 215, 249, 309
  non-verbal 175, 196–197, 201
  repeated 198, 200, 309
sound/music 30, 176, 198, 202
source domains, strategic use of 23, 283, 307
source-path-goal schema 130
  see also path-goal schema
space
  metaphoric 131–132, 232
  temporal 123–124
Spaeth, G. L. 147, 158, 170
Spanish texts 141, 149, 152–153, 155, 158, 160, 164–165, 167–168, 171, 185, 190
spatial relations 76, 95, 124, 242, 300
speakers 9, 114–115, 120, 132, 274
specialised knowledge 185, 188
specialists 10–11, 23, 26, 212, 215, 228–229, 297, 303, 307, 314, 316
species 15, 46, 54–55, 57, 60, 181, 185, 190–191, 203, 309
  individual 60, 185, 190
  microbial 54–55, 60
  non-human 191, 194–195, 203
speech 66, 115–116, 132, 196
squid 54–56
state
  alternative equilibrium 77, 86, 92, 94, 248–249
  conceptual mappings 22, 66, 77, 97, 191, 216, 245, 249, 256, 271
  configurational 104–105
  macro 245, 248, 310
  quiet 105, 244, 251
statistical analysis 222, 224, 227–228, 231, 251, 253–254
statistics 220, 222, 225–226, 228–229, 231, 233, 237, 242, 254, 257, 299, 304
Steen, G. 8, 11–13, 22, 24–27, 36–37, 65–67, 71, 114–115, 136–137, 213, 216, 266–269, 294–295
Steinhart, E. 214, 216, 260, 303, 318
stem cells 121, 138
stepping stones 216, 218, 303, 316
stereotypes 15
Stock, G. 122–125, 131, 134, 137–140
Stomach Example by Searle 60, 265, 271, 276, 278–279, 282–293
stories 99, 120, 132, 202, 225, 257, 265, 272–275, 277, 281, 310
story understanding 271–274, 276, 279, 281
strategy 103–104, 165, 190, 195, 197, 201
strong AI claim 271, 291
strong subject matter theory 254, 257
structural elements 14, 52, 65, 115
student learning 98–99, 292, 303
students
  female 289
  university 93–94, 105
  weaker 292–293
stylized facts 226–227, 229
subclass 181
subjectivity 189, 198, 309
sub-mappings 77, 80–81, 85–87, 105, 218, 221–222, 224, 234–236, 240, 243–244, 247, 251–252, 254–255, 306, 309
  conventional 238
    see also metaphor, conventional
  integrated 20, 30, 179, 211, 219, 240, 243, 253–254, 303, 312
subclass 181
subjectivity 189, 198, 309
substance
  metaphor 3, 47, 67, 76, 81–84, 86–87, 90, 98–99, 103, 303
  ontology 90, 99, 222, 224, 233
  signaling 55
subsystems 45, 278
successes in explaining science 18, 61, 103, 122, 187, 252, 300, 302, 310

suicide, committing 141–142, 145, 147, 150–161, 163–164, 168
supervenience 28, 41, 45, 47–48, 57, 60–61, 68
surface manifestation of mapping 5, 232
survival 46, 50, 59, 145, 157, 164, 191, 193, 202–203
  see also metaphor, dramaturgical
suspects, criminal 222, 224, 226–227, 229–231, 248, 253
swaying, *see* algae metaphor
symbionts 57
symbiosis, social metaphor 55–57
symbols 16, 236, 274, 281
system
  elements 81, 242
  thermodynamic 84–86, 93–94, 99, 104–105
systematic metaphor analysis 61, 65, 68, 77, 79, 81, 86, 93, 100, 106, 113, 115, 119
  see also metaphor, analysis
system stability 131, 236, 244–245, 247, 249–250

T
tabulations 224–226, 232, 253
target domain
  unfamiliar 12, 19, 307
  complexity 19, 272, 310
  context 18, 272, 275
  elements 5, 15, 279, 286, 288
teachers 19, 28–29, 66, 74, 101, 103–104, 214, 257, 314
teaching students 1–3, 17, 19, 31, 63, 66, 100–101, 103–106, 195, 202, 303, 309
technology 114, 117, 120, 122, 124, 126, 129, 131
  contested 114, 117
  new 113–114, 117
  related to science 113, 119, 123, 127, 132, 185, 311
teleology 28, 41, 45–50, 57, 61, 68, 306
temperature 75, 84–85, 88–90, 98–99, 185, 300
terminology 10–11, 147–148, 199, 201, 213, 215, 239, 315
  scientific 167, 177, 184
texts
  academic 29, 73–76, 84–85, 88, 94, 102, 118, 219, 267, 285
  original 117, 121, 132, 292, 311
textual evidence 153, 156, 159, 161, 164, 168, 176, 199, 202, 212, 219, 223
thermodynamics 28, 75, 79, 84–87, 94, 98, 105, 302
thought processes 12, 64–65, 282
Tiers, E. T. 57, 71
time 9, 11–12, 42–44, 46, 48, 106, 127, 130–132, 149–150, 185, 192–193, 198, 226–228, 233–234, 239–245, 247–248, 250, 255, 301–302, 307–308
  geologic 17
time-stable individual differences 232
tools 28, 56, 62, 113, 213, 221, 224, 239, 293, 315
  computational 215, 304
topic 2, 5, 21–22, 85, 87–88, 93, 114, 215–219, 251–253, 284–285, 292–293, 298–299, 303–304
  see also target domain
  given 268
  important 175
  main 168
  respective 293
  unfamiliar 20
trajectory 236, 243, 246–250
transfer 75–76, 79–80, 84, 86–87, 89–91, 93, 97, 115, 183, 313
  conceptualizing 96, 98, 105
transformation 79–80, 82–84, 86, 93
tropes 11, 25
truth 61–62, 69, 131, 204–205, 264, 278, 280, 283, 314
tumours 153–157, 161, 163
turbulence 244
Turner 33, 35, 78, 108, 110, 258, 260, 317
types of metaphor 11, 15, 17, 25, 27–28, 141–142, 153–154, 177–178, 180, 187, 189, 192–194, 197, 201–202, 204

U
understanding
  accurate 1, 21, 106, 142, 217, 230, 265, 292
  audience's 10, 12
  comprehensive 147, 237, 303, 316
  micro level 256, 311
  public's 7, 30, 63, 197, 233–234, 239, 300, 316
  scientist's 49, 60, 212
United States 131, 221, 226, 282, 284
universe 49, 84
Ureña Gómez-Moreno, J. 30, 176–177, 184, 191, 193, 199, 201, 206–207, 300, 309–310

V
Vallacher, R. 232, 239, 243, 245–246, 250, 261–262
value of metaphor 2, 8, 28–29, 102, 106, 187, 191–192, 231, 237–238, 302, 304, 310–311
variables 3, 62, 87, 92, 222–228, 231
  confounding 226, 228
  dependent 222, 224, 226–227
  extraneous 227, 253
  independent 85, 222, 233, 239
verbalization 176, 197, 199, 201, 227
verbs 157–158, 168
video clips 20, 30, 51, 175–176, 184, 188, 191, 194, 198–199, 201–202, 227
viewpoint, shift audience 15, 117, 194–199, 201–202, 204, 217, 302–303, 316
  see also perspective, change in
virulence 58–59
vitalism 47–48, 241

W
Watts, D. M. 96–97, 110
Weinrich, H. 115, 121
wholes, properties of 48, 130
Williams Camus, J. T. 30, 141–142, 144, 146, 148, 150,

152, 154, 156, 158, 160, 162, 164, 166, 307–308
Wordsmith Tools 149
world, natural 56, 61–63

Z
zombies 162
zoosemiotics 191, 192, 195, 204

Metaphors are essential to scientists themselves and strongly influence science communication. Through careful analyses of metaphors actually used in science texts, recordings, and videos, this book explores the essential functions of conceptual metaphor in the conduct of science, teaching of science, and how scientific ideas are promoted and popularized. With an accessible introduction to theory and method this book prepares scientists, science teachers, and science writers to take advantage of recent shifts in metaphor theories and methods. Metaphor specialists will find theoretical issues explored in studies of bacteriology, cell reproduction, marine biology, physics, brain function and social psychology. We see the degree of conscious or intentional use of metaphor in shaping our conceptual systems and constraining inferences. Metaphor sources include social structure, embodied experience, abstract or mathematical formulations. The results are sometimes innovative hypotheses and robust conclusions; other times pedagogically useful, if inaccurate, stepping stones or, at worst, misleading fictions.

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